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TWO NEURO-MUSCULAR INDICES OF MENTAL FATIGUE

BY G. L. FREEMAN AND S. B. LINDLEY *

Northwestern University and Yale University

Although the study of the neuro-muscular processes involved in fatigue lags behind the measurement of output we have progressed beyond that naive position which regarded Mosso's experiments as 'epoch-making' and the isolated nerve-muscle preparation as 'indispensable' in explaining work decrements. Dodge [1] gives four criticisms of the inadequacy of this paradigm, as follows: (1) nerve tissue *in situ* is quite resistant to fatigue, (2) the effect of normal psycho-physical rhythms is excluded, (3) the constantly changing stimuli of mental work are ignored and (4) the effect of incidental inhibitions is excluded. Taking the matter of changing 'inner stimuli' as the most characteristic feature of mental fatigue, Dodge makes work decrement relative to the intensity of these reinforcing agents. The laws of relative fatigue developed from a consideration of the effect of the relative refractory phase of nervous tissue on the one hand and of competition and rivalry for the control of the final common path on the other. Then there can be true fatigue of neural tissue without accompanying work decrement. Output may even increase

* From the Psychological Laboratory of the Institute of Human Relations. The work was done while the senior author was a National Research Council Fellow. He wishes to express his appreciation to the Fellowship Board as well as to Prof. Raymond Dodge who read the manuscript critically.

[1] R. Dodge, The laws of relative fatigue, *Psychol. Rev.*, 1917, 24, 89–113.

under the autogenetic reinforcements which become operative as the original neural paths fatigue.

While this positive advance has met with widespread acceptance, it raises many questions of detail. One of the most important concerns the constellation of actual reinforcing agents and their several effects in the economy of neural operation. The relation of such factors as degree of effort, incentive, attitude and the like to either the absolute or relative fatigue of neuro-muscular centers is quite obscure. Myers [2] differentiates between protopathic exhaustion and epicritic adaptation—this last covering the 'continued sets of control and direction.' The majority of mental work decrements are thus determined by a disturbance in the 'balance of neural control' or the 'fatigue of direction.' Johnson,[3] on the other hand, stresses the importance of muscular reinforcement to mental activity,—mental fatigue being regarded as akin to some degree of muscular exhaustion. It is evident to the reader of these two recent theoretical contributions that neither analysis carries much further than that made by Dodge. Although both serve a purpose in emphasizing certain aspects of the problem, the question of how the neuro-muscular mechanism operates to produce the presence or absence of work decrement awaits adequate experimental investigation.

The majority of fatigue experiments are still confined to measuring those particular consequences of continuous work traditionally known as changes in output. The only justification for this procedure is its convenience. The measurement of correlative changes in neural activity is packed with problems which we have no adequate techniques to investigate. But this is no excuse for ignoring how the organism behaves as a whole during the work period. Neither 'output' nor metabolic factors can be taken as exclusive indicators of diminished returns. The most sensible criterion would be some sort of ratio between the two. We cannot talk, however, in terms of such 'efficiency quotients' until the measures of neural activity can be defined as definitely as those of performance. While

[2] C. S. Myers, Conceptions of fatigue and adaptation, *Psychol. Rev.*, 1925, 31, 1–16.

[3] H. M. Johnson, The real meaning of fatigue, *Harpers*, 1929, 144, 1–8.

no satisfactory expression is immediately to be expected, appropriate research in the neuro-muscular processes will presumptively advance our knowledge of the organic aspect of fatigue.

Our immediate experimental task may now be briefly defined; the study of two types of neuro-muscular activity, (1) muscular tension or tonus and restlessness and (2) their relation to each other and to the curve of continuous work. Through an understanding of such relationships we aim toward a more refined conception of the conditions of mental fatigue.

The appropriateness of the variables chosen for our study is easily appreciated. The prospective investigator of the central neural activity of the intact human is faced with an immediate dilemma: there are three possible types of indicator to chose from (conscious processes, overt behavior and neural energy transformations), the relative value of which to physiological interpretation is the exact inverse of their order of technical adequacy. Conscious processes, though easily reportable, have not appreciably advanced our knowledge of fatigue. Overt behavior, which may be 'objectively' measured by suitable instrumentation, leaves much room as to its interpretation. No adequate technique for the analysis of complex energy-transformations has yet been devised for use with humans. In the face of such difficulty, we felt that a combination of indicators would be a step in advance. The importance of slight postural shifts as evidence of fatigue is too well recognized to require justification.[4] Muscular tension, on the other hand, has not been used extensively in the study of neural activity. Whereas the difficulties of metabolic measurement have led to the use of pulse, breathing and the galvanic skin reflex as indicators, tonus has been exploited mostly through the indirect medium of the tendon reflexes. In spite of its consequence in the economy of central nervous operation,[5] the direct relation of tonus to the dynamics

[4] C. H. Myers, Industrial psychology, *Peoples*, New York, 1925, 39–75.

[5] Space does not permit a review of the pertinent literature. The more important studies are listed by G. L. Freeman, The measurement of tonus by deformation of the tendon, *American J. Psychol.*, 1930, **42**, 581–592.

of mental work and fatigue has remained relatively unexplored. This has resulted not so much from arbitrary neglect as from the technical obstacles encountered in the measurement of tonus. The method of tendon deformation, recently described by one of the writers,[6] meets the more serious of these difficulties. The use of this method, in combination with records of general restlessness and reports of conscious behavior, provides a useful index of central nervous change. Following a description of our experiments, we shall return to the question of physiological interpretation.

The Plan of Experimentation

Our experimental study was divided into two parts; In Exp. I we sought the relationship of quadriceps tension, restlessness and conscious behavior to the period of work. Three undergraduate subjects worked for three consecutive days with three diversified tasks. Each task was carried out for a period of 5, 15 and 45 min., the tests being arranged in counterbalanced practice order, as follows:

Schedule Showing Counter-balanced Practice Order (Exp. I)

Subject	Practice Order		
	First Day	Second Day	Third Day
Mahon	5 min. of test 1 15 min. of test 2 45 min. of test 3	5 min. of test 2 15 min. of test 3 45 min. of test 1	5 min. of test 3 15 min. of test 1 45 min. of test 2
Lazar	5 min. of test 2 15 min. of test 3 45 min. of test 1	5 min. of test 3 15 min. of test 1 45 min. of test 2	5 min. of test 1 15 min. of test 2 45 min. of test 3
Fox	5 min. of test 3 15 min. of test 1 45 min. of test 2	5 min. of test 1 15 min. of test 2 45 min. of test 3	5 min. of test 2 15 min. of test 3 45 min. of test 1

The three tasks, later to be described, followed each other at approximate 5 min. intervals. A conveniently located clock allowed the subject to keep track of his time. For the longer period of work the experimenter remarked when 'only five minutes more' remained to the end. As a means of

[6] *Ibid.*

securing uniform motivation, subjects were paid for their services.

The instructions were:

"We shall measure your performance of several tasks over various periods of time. The experimenter will explain each task fully and tell you how long you are to work. Set yourself a good stiff pace when the 'ready' signal is given and then keep at it until time is called. The clock is for your convenience in watching the time.

"Sit as quietly as possible while the apparatus is being adjusted. Be particularly careful not to move your legs during the tests. Changes from an uncomfortable position should be made between tests.

"At the end of the experimental hour you are asked to comment on your experiences during the tests. Do not let the thought of reporting hinder the efficiency of your performance. It is easy to tell how you felt."

In Exp. II we sought to study the relations of our several variables by more extended tests. Our three subjects now worked on each of the tasks for five consecutive days. Each experimental session lasted one hour and thirty minutes and was carried through without rest pause.

Added instructions were:

"This time we are going to let you report your experience during the course of the tests. But do not let this interfere with your work. All we wish to know is when your mind wanders from the task at hand. When this occurs, characterize the mental activity by a word or phrase, for example, 'looking at time' or 'thinking of a friend.' It is quite necessary that your legs remain immobile during the tests."

Because our subjects were without previous psychological training, their reports cannot be considered fully satisfactory. The comments were necessarily sketchy and brief. The attempt to obtain an elaboration of significant items at the end of the hour aided in some cases.

In both Exp. I and Exp. II the subjects worked at approximately the same hour of day. Although urged to keep their ways of living as uniform as possible, temporary aberations were reported by all.

The Performance Tests

The performance tests were representative of various levels of neural integration. The first, *finger renitence*,[7] primarily involved the local fatigue of a single muscle group. The second, *finger oscillation*, involved not only local muscular fatigue, but also a disturbance in the balance of a finely adjusted neural organization. The third, *mental addition*, involved a still higher neural systematization. The nature of each test is described in detail.

1. Our measure of *finger renitence* consisted in the resistance of the subject's right index finger to the pull of a one thousand gram weight (the *sublimis digitorium flexor* presenting a more or less persistent renitence against extension by the attached weight). Continued resistance to a pull of this sort has certain advantages over ergographic work. In finger renitence a single muscle group is acting constantly. In ergographic work reciprocal innervation of agonist and antagonist allows a period of rest in the relaxing muscle group. In other words, muscular exhaustion in ergographic work is complicated and may be delayed by the conditions used to obtain it. The simpler neural organization operative in finger renitence presumptively makes a clearer experimental picture. Here is a performance which, once initiated, can be carried on at almost a reflexive level.

The subject was seated in a morris chair with his arm and hand strapped in a comfortable position. A metal cap was placed over the free index finger. The weight to be resisted acted on this cap over a pulley. The cap was so constructed that it covered both upper-joints, thereby distributing the weight evenly along the finger. This arrangement also avoided changes in leverage occasioned by shifts in the joints of the member. The mechanism through which the weight acted was concealed from the subject, his only cues of a 'break' being kinesthetic and auditory. The auditory cue sounded only when the weight actually overcomes the pull of the

[7] We introduce this new term with some hesitancy. Renitence means properly 'presenting a continuous resistance to pressure or the effects of it.' Renitence may be distinguished from dynamometric work in which the muscle usually presents a discontinuous maximal resistance to the effects of a super-maximal pull.

subject's finger. Hence the regulation of the necessary amount of finger pressure came from a proprioceptive cue.

At the ready signal, the subject pressed downward with his finger to resist the weight as it was applied. He was instructed to keep his finger (and the weight) as stationary as possible. Failure in this task is reported by the clicking of the ratchet device which acted to prevent the subject from pulling the weight back to its original position; that is, the subject was expected to arrest the upward pull on his finger as quickly as possible. The ratchet device served to record such 'breaks.'

2. *Finger oscillation* has proven especially suited to the study of fatigue.[8] In our experiments the subject oscillated his right index finger, —the arm and hand being held as in the previous task. Rapid oscillation cannot be continued as uninterruptedly as can a slower pace. While this was not explained to the subjects, they were told that periods of total inability to oscillate the finger would 'pass off' and normal speed regained with comfort if they 'kept on trying.'

3. *Continuous addition* is a performance typical of those studies where output is the sole index of diminished returns. Although involving a higher level of neural systematization than our other tests, its conditions of operation are much less understood. Poffenberger [9] has shown, however, that it has advantages over all other tests of the 'higher' functions: These he gives as (1) presumptive exercise of a single function, (2) standard material available in sufficient amounts, (3) unlike mental multiplication—there is little improvement from practice and the discovery of short-cuts and (4) less opportunity offered for 'let down' or rest than with more complex and varied performances. We used the addition sheets prepared by Dunlap [10] in our tests. The sum of 15 four-place numbers were entered in the booklets supplied, the subject signaling each total.

[8] R. Dodge, *op. cit.*

[9] A. F. Poffenberger, The effects of continuous mental work, *Amer. J. Psychol.*, 1927, **39**, 283–296.

[10] K. Dunlap, Adding Machine Material, Johns-Hopkins, Baltimore, 1929.

The Recording Apparatus

Performance, restlessness and tension of the quadriceps muscle were simultaneously recorded on 6-inch wrapping paper. The recording mechanism was, essentially, a polygraph having three electromagnetic markers and a means for tracing the optical movement of the tonus record as indicated. The instrumentation necessary to obtain the several records was sufficiently elaborate to require the presence of both investigators during the experimental sessions. Responsibility was divided as follows: one experimenter traced the tonus record and took the subject's running commentary: the other experimenter gave instructions, kept time and constantly checked the functioning of the several units which made up the apparatus. The details of these units are given below.

The Polygraph.—This mechanism consisted of a kymograph drum which was revolved horizontally on appropriate bearings by a small electric motor suitably geared down, and moved a strip of wrapping paper 6 inches wide. The paper passed from the supply roll, over the top of the drum, between the drum and roller to insure proper traction and then on to the floor where it was allowed to accumulate during the experimental period. The speed of this passage usually approximated five mm per sec., although the rate could be varied by changing the speed of the electric motor.

Directly above the drum surface, a platform was arranged to carry the recording pens. The pen tips rested in the sockets of small aluminum levers. Electro-magnets actuated these levers. Simultaneous records of lever movements were easily obtained since the pen points worked along a horizontal beveled brass bar, placed at right angles to and about two mm above the moving paper. The three markers recorded, respectively, time (in sec.), restlessness, and work output. Tonus changes were recorded by tracing the movement of a beam of light, reflected from an optical lever, along the brass bar.

The Tonus Indicator.—This was essentially the same as described in a previous communication.[11] It consisted in a

[11] G. L. Freeman, *op. cit.*

lever, serving to deform the patellar tendon, appropriately attached to an optical lever. The system magnified the changes in tendon deformation approximately 150 times. By use of plane mirrors vertical movements of the recording beam from this optical lever were made to play along the horizontal brass reference rod of the polygraph. This device is much the same as that employed in manual recording of galvanometric fluctuations. And since true tonus changes are characteristically slow, these movements were easily followed with a pencil.

In order to facilitate the scoring of tonus changes, a grid made of small copper wire 5 mm apart extended in front of the reference bar for a distance of 90 mm. Passing the pencil over these wires made breaks in the curve, as shown in Fig. 1. (The grid was used in Exp. II only.) Although these units of measurement are somewhat gross they were sufficiently exact for our purposes.

Artifacts produced by quick movement of either leg usually appear in the record of tendon deformation as sharp rises or declines and are quite distinct from the slower tonus changes. Nevertheless, a further check was found desirable in order to correct our curves for such effects. In the present experiment leg displacement was given magnification equivalent to the changes it produced in the tendon record. This was possible by fastening an auxiliary optical lever on an independent standard and connecting it with the tonus recorder in the usual manner. The height of the subject's limb was adjusted to fit a standard setting of the tendon apparatus. Individual footrests were constructed which brought the place of greatest tendon deformability opposite the point of the depressor. By placing three mirrors about the axis of the optical lever at the tendon, the amount of necessary adjustment during work periods was notably lessened. These mirrors were so arranged that as the reflection of one left the record surface the reflection of the next adjacent appeared. In practice the preëxperimental setting was made by the middle mirror.

The Restlessness Indicator.—A simple device for recording restless movements of the trunk and shoulders utilized, as its

essential feature, the Lindley rotary switch.[12] The switch was placed in series with one of the electromagnetic markers of the polygraph so that each contact 'made' the circuit. Contact at the switch was made by movements of a thread over a metal cylinder. The thread was attached to the subject's left shoulder coat-seam and was held taut over the cylinder by a small metal weight suspended at its free end. Slight movement of this string in either direction caused a lever attached to the rotating cylinder to connect with one of the silvered contact points. In our experiments the contact points were set 2 mm. apart.

It will be appreciated that either steady or jerky movements in one direction only will effect the switch once—(the hanging weight taking up the slack of the string). But this deficiency seems to be offset by the success obtained in measuring slight back and forth movements. It seems probable that such shifts are more characteristic of restlessness than are steady changes in posture.

The Time Recorder.—Time was recorded by an electromagnetic marker in series with a second pendulum. Since none of our markers acted silently, we have inadvertently introduced sounds which may have induced a rhythmic performance. Gross inspection or our records indicates, however, little ground for this supposition. The armatures were fastened by string to one end of the alluminum levers on the polygraph. Appropriate springs returned the levers to a resting position following each pull of a magnet. Bent glass tubing was found to be a successful substitute for pulleys in engineering the mechanics of these systems.

The Performance Recorders.—The third magnetic marker served to record all performance scores. The circuit through this marker could be easily attached to the switches employed in the several performance tests. The switch used to record finger oscillations was clamped into position beneath the index finger so that every depression of the thread (which passed over the switch cylinder) closed the recording circuit. At every upward finger movement an elastic tension brought the

[12] S. B. Lindley, A rotary electric switch, *J. Gen. Psychol.*, 1931, **5**, in press.

thread back to its original position, opening the rotary contact switch thereby. While this mechanism does not measure the amplitude of oscillation, it presents an *important* advantage in freeing the finger from the discomfort of restraining harnesses.

The switch just described was also used by the subject to signal the completion of addition problems. The mechanism used to record breaks in finger renitence differed from this in important particulars.

The character of the tests of finger renitence was the same in both our experiments, although we were forced to substitute a new device in Exp. II. It will be recalled that in the first experiment, the cord connected with the finger worked over the axis of a ratchet wheel. In Exp. I the 1000 gram weight acted on the same axis to turn the wheel in the direction opposite to that produced by the downward pull of the finger. Every movement of the weight downward raised the ratchet pin which then closed an electric circuit. Since the subject was instructed to arrest the downward movement of the weight (upward movement of resisting finger) we had a record of the duration as well as the time of his lapses. The notable drawback of this system was that the ratchet arrangement did not permit the return of the finger to its position prior to a 'break.' Sufficient 'breaks,' therefore, pulled the member so far backward that severe pain was experienced. The subsequent readjustment took from 15 to 30 sec. Since the weight was off the finger during this time, an uncontrolled rest pause was occasionally introduced.

The device used in Exp. II eliminated the uncontrolled rest pauses and permitted the subject's finger to remain stationary during work. Here a brass chain from the finger passed over the shaft of a small D.C. electric motor and was fastened solidly below. By setting a varied resistance in the motor circuit a predetermined amount of torque was produced. (The torque of the motor shaft varied directly proportionally with the strength of the current allowed to enter the motor; *i.e.*, torque of 250 gms. required 15/100 amp., 500 gms.—18/100 amp., 750 gms.—21/100 amp.) In our experi-

ment the necessary downward pressure required to counteract the torque was 250 gms. The subject was instructed to keep the motor shaft from turning and to arrest the movement as soon as possible in case of lapses. The revolutions of the motor during such 'breaks' were recorded by a rotary switch in circuit with a magnetic marker. A fine thread passed around the axis of the switch and over a slight excentricity on the motor shaft. Every turn of this excentric made a contact at the switch. This mechanism was able to record as high as 1100 r.p.m.—a number far in excess of our experimental demands. The click of the contact switch at every revolution was the subjects cue for speedy recovery.

Summary of Experimental Precautions and Controls

Before describing our results, we shall recapitulate briefly the numerous precautions and controls employed to secure the reliability of our records. It goes almost without saying that our combined study of tonus, restlessness, conscious behavior and output demanded an exacting experimental regime. Two types of precaution were necessary, (1) control of the subject's attitude and (2) apparatus controls.

(1) Only a partial control over subjective attitude can be established in any psychological research. The traditional maxim that the simpler the experimental situation, the better the control admittedly works to the discredit of our own research; for seldom is a subject introduced into a more complicated apparatus. One leg is stabalized with a lever pressing upon the tendon. Something else is hooked on the shoulder. The right arm and hand are secured; and the entire mechanism looks generally forbidding. Physical discomfort, curiosity about the mechanism and fear of mal-treatment,—these and other disturbing attitudes may be easily induced. Previous experience with subjects in complicated apparatus has not been without benefit to the writers. By way of freeing the situation of the excitants to disturbing cortical action, we adopted the following procedures. (*a*) The subject was led to regard the apparatus as a relatively simple mechanism, (*b*) if he showed any curiosity about the details they were 'ex-

plained' in a word, (*c*) time was allowed for the subject to become adjusted to the 'feel' of his restraining bonds before actual experimenting began, (*d*) practically all the recording apparatus was concealed by a curtain during the tests, (*e*) the nature of the experimenter's activity was also concealed by the same curtain, (*f*) thus the subject was not excited by any slight malfunctioning which might occur in parts of the apparatus and finally (*g*) a check on all the conscious shifts of the subject was obtained by free and directed report. These procedures should go a long way toward compensating for the complicated experimental setting. The subject's reported themselves very comfortable once they became adjusted to the apparatus. In fact, so little of interest was presented during the more monotonous tests that difficulty in keeping awake was experienced. It is our opinion that the methodological precautions of this research introduce fewer distracting cortical conditions than do experiments employing the introspective techniques alone.[13]

(2) The recording units were oiled and checked prior to the daily tests and their proper functioning was guarded during each session. Most adjustments could be made without disturbing the course of the experiment. Fresh recording pens could be quickly substituted; the speed of the record paper was altered by reostat; two separate sources of current were available; the effect of leg displacement on the tonus curve was compensated for as much as possible. Briefly, the constant attention of two experimenters to such details produced a high degree of reliability in the records obtained.

The Records and Their Scoring

Figure 1 reproduces a section of a record taken during a test of continuous finger renitence. The record is typical of all tests; *a* is the time line (in seconds), *b* shows the restless movements of the trunk and shoulders, *c* indicates the lapses in finger resistance, *d* is the tonus curve, *e* shows the extent of leg displacement, *f* is the subjects commentary written on the record as it passed through the polygraph.

[13] *Cf.* J. C. Flügel, Practice, fatigue and oscillation, *Brit. J. Psychol., Monog. Supp.*, 1928, 13.

Certain arbitrary decisions were necessary in scoring the records. Our measures of restlessness, performance and tonus will be recognised to have relative status only. Restlessness and performance could be easily scored by counting the number of 'jags' which occurred in each record per unit of time. In the case of the tonus curve it was necessary to establish

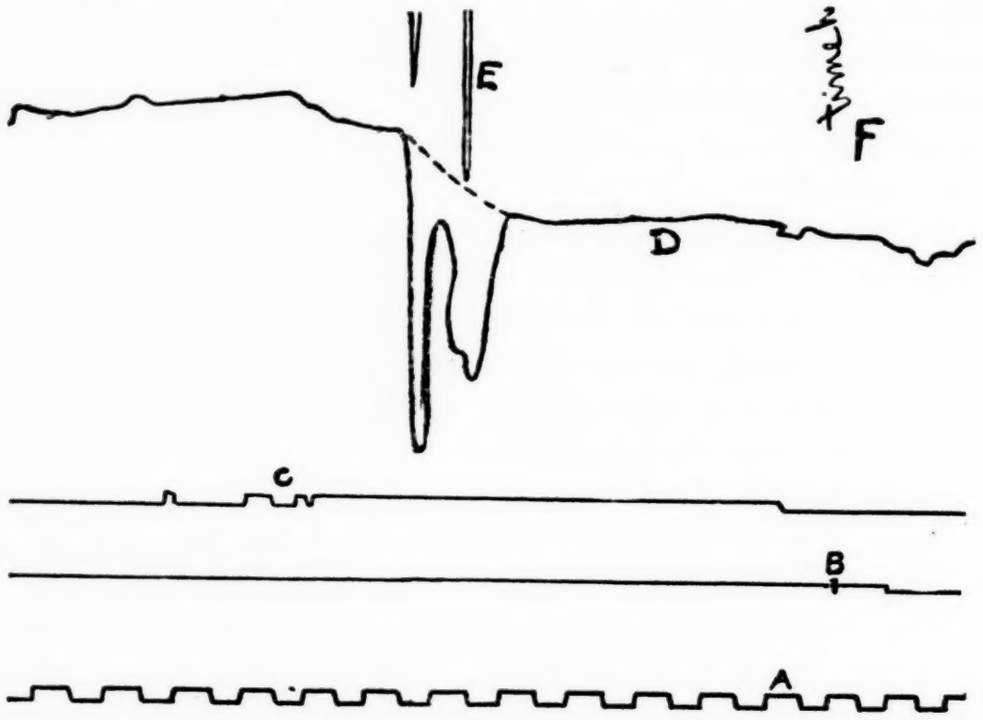

FIG. 1. Sectional record of finger renitence (Subject *M*) showing tonus, performance and restlessness.

some base line from which the mean height (in mm) could be reckoned for this period. This base line was supplied by the position of the tonus curve immediately preceeding the tests. In the event that this fore-period was occupied by an anticipatory increase in tension (instead of the relaxation phase usually recorded), an attempt was made to establish the base line prior to such increase. Artifacts produced by leg displacement were canceled by subduction. The suppositious true tonus curve during leg displacement in Fig. 1 is shown by the dotted line.

While we desire to express our results in units suited to the accuracy of our data, we do not wish to become too involved in statistical procedure. We have thus chosen to compute the

average changes per second for units of 30 sec. (Exp. I) and 60 sec. (Exp. II).[14] The averages will be given the form of curves without statistical elaboration. Variability will not be treated as extensively as formulae allow and statistical correlation between the several measures will not be attempted. Such mathematical treatments are undoubtedly of value. It is our opinion, however, that in this presentation our data should be kept close to their raw state. Because of their possible significance in future research, these data have been retained in their entirety. They may be consulted [15] by those desiring to apply more refined methods of mathematical treatment.

The Charts

Our records are summarized in the form of charts. (Figs. 2, 3, 4, 5, 6, 7.) Each chart shows each individual's performance, restlessness and tonus curves for a given test. The abscissa on all the charts represent time units and the ordinates represent the scores. A reference to Fig. 2 will show the principle of chart construction. The lowest group of curves on the chart exhibits the tonus changes (of the three

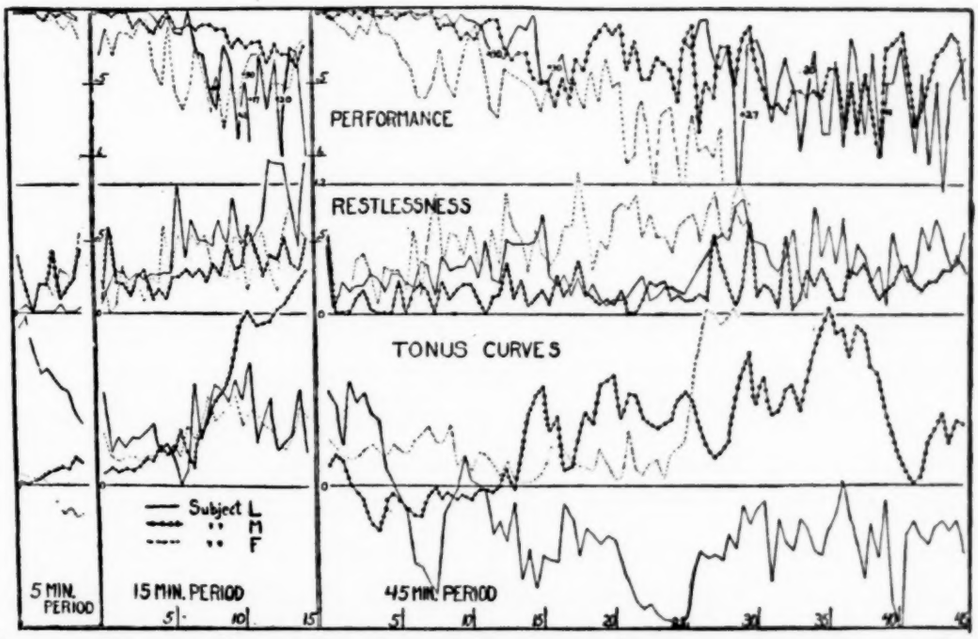

FIG. 2. Finger renitence, Exp. I; performance, restlessness and tonus curves for 5, 15 and 45 min. work periods.

[14] The units selected were as small as the exigencies of chart construction allowed.

[15] Data file of the Institute of Human Relations, Section of Psychology.

subjects), the middle group the restlessness and the upper group the equivalent performance scores. Since the time unit is the same for all curves, it is possible to compare these scores roughly on the chart. The small size of the charts does not permit the reading of precise scores. These charts were originally drawn on mm cross section paper with the following scale, —5 mm, 30 sec. (in charts 5, 6, and 7—7 mm equals 60

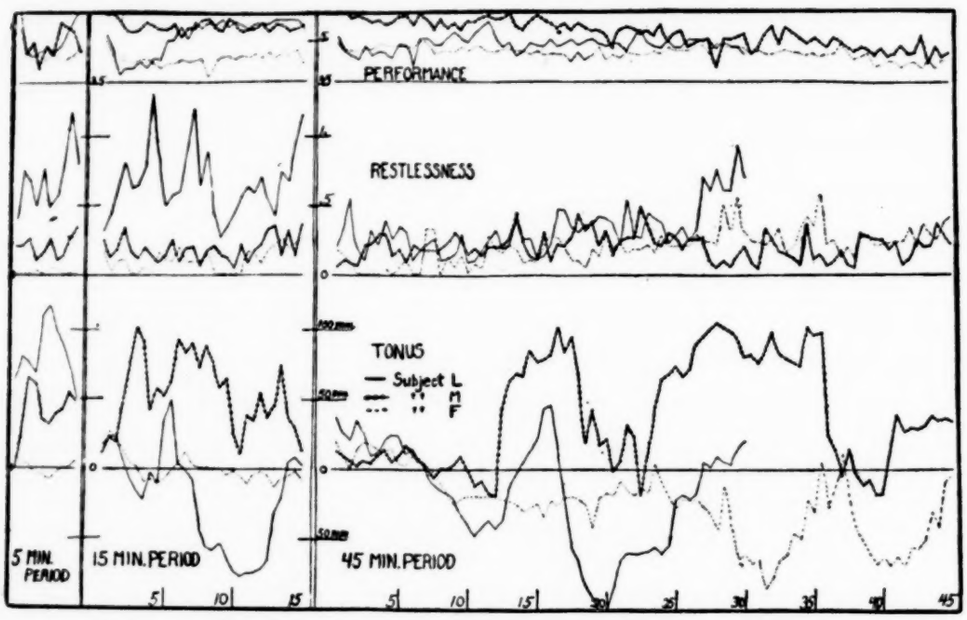

FIG. 3. Finger oscillations, Exp. I; performance, restlessness and tonus curves for 5, 15 and 45 min. work periods.

sec.), 1 mm—1 mm of tonus change, and 1 mm—.01 restless movements. All charts are one fourth reduced.

Figure 2 shows the tonus, restlessness and performance curves for test of finger renitence (Exp. I), the results of the 5, 15 and 45 minute tests all being given in this same chart. Figure 3 does likewise for (Exp. I) finger oscillation. Figure 4 summarizes the results of (Exp. I) continuous addition, Figs. 5, 6, and 7 show respectively the composite curves obtained in Exp. II for finger renitence, finger oscillation and addition.

RESULTS (EXP. I)

The results of Exp. I will first be treated in respect to the type of performance tested. We shall discuss in turn the relation of restlessness and tonus to the performances of (1)

finger renitence, (2) finger oscillation and (3) continuous addition. Following such presentations we shall pass to the consideration of (4) the relation of our neuro-muscular indices to the period of work, (5) variability and (6) individual differences in the curves. The interrelation between the several measures will be more fully discussed in connection with Exp. II.

The Test of Finger Renitence (*Fig. 2*).—The three curves in

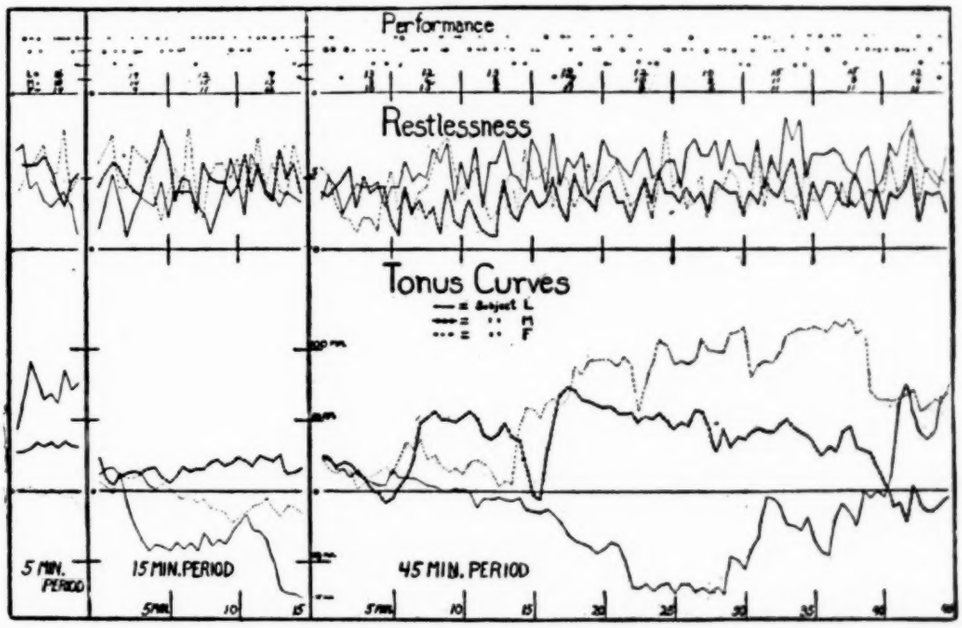

FIG. 4. Addition, Exp. I; performance, restlessness and tonus curves for 5, 15, and 45 min. work periods.

the upper section of the graph represent the average number of lapses in finger renitence per second (for units of 30 sec.). We find a marked decrement in both the 15 and 45 min. performances. Some of the major irregularities in these curves were produced by readjustment of the apparatus and the consequent intervals of rest for the subject. Such 'rest periods' are indicated on the chart by an asterisk. The number beside the asterisk gives the time (in sec.) during which the load was off the finger. It is interesting to note that renitence improves following each rest period. That this recovery is far from absolute is shown by the progressive decrement in the 'spurts' following rest.

It will be noted that during the 45 min. period *L* did no

work between the 16th and 25th min. and that *F* stopped working after 30 min. Both of these defects were due to technical troubles. Since subject *L* was not informed that the apparatus was out of order, it will be interesting later to note how he behaved during this part of the test. For the present

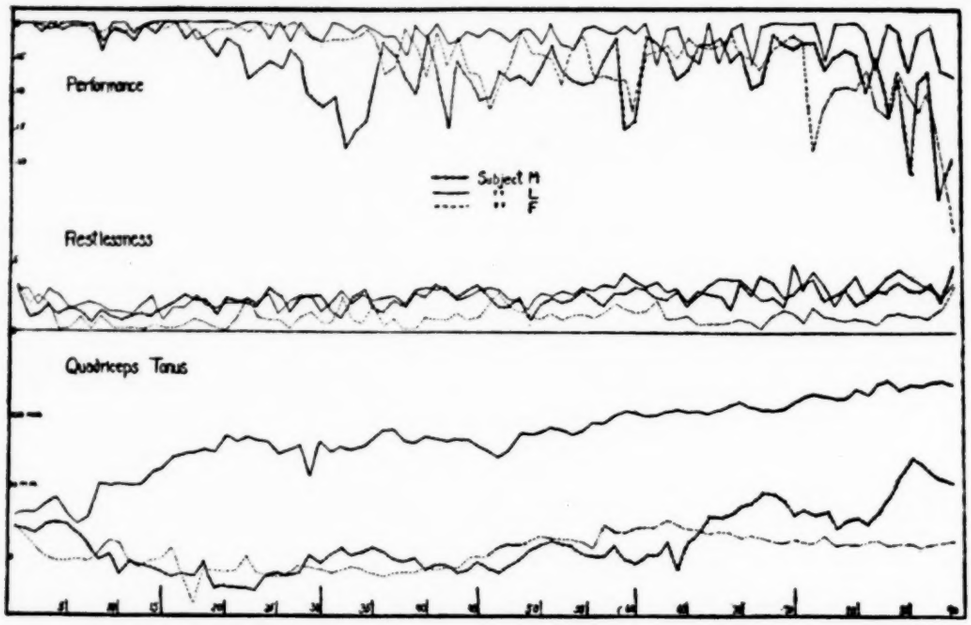

FIG. 5. Finger renitence, Exp. II; composite performance, restlessness and tonus curves for 5 consecutive 90 min. sessions.

we shall simply point out that his performance was much improved following his 'rest.'

It will be appreciated at a glance that our accidental rest periods do not entirely account for the oscillatory character of the performance curves. The question immediately arises as to whether there is any periodicity in performance-oscillation.[16] If there is any such periodicity in these or any of our other work curves, the factor is not evidenced in the present arrangement of the data.

The middle group of curves in Fig. 2 shows the tendency for restlessness to increase with time. A more detailed study reveals relatively high restlessness immediately on the initiation of the task.

[16] The problem of periodicity in work-output has been discussed by R. Dodge (Elementary conditions of human variability, Columbia University, New York, 1927, 79–101), and by R. H. Wheeler (The Science of Psychology, Crowell, 1929, 306). There is as yet little decisive evidence of true periodicity. The most rhythmic variations found in Flügel's extended study (*op. cit.*) were artificially produced by the timing of the performances.

The most striking feature of the tonus accompaniments of finger renitence (3d section of the graph) is their evidence of individual differences. This will be discussed in a later section. At the present we are concerned in such characteristics as are consistent among the three subjects. From the curves we note (1) the period of heightened tonus at the beginning of work and its gradual decline and (2) the succeeding series of extensive arrhythmic changes. While there is no statistically reliable correlation between these later increases and per-

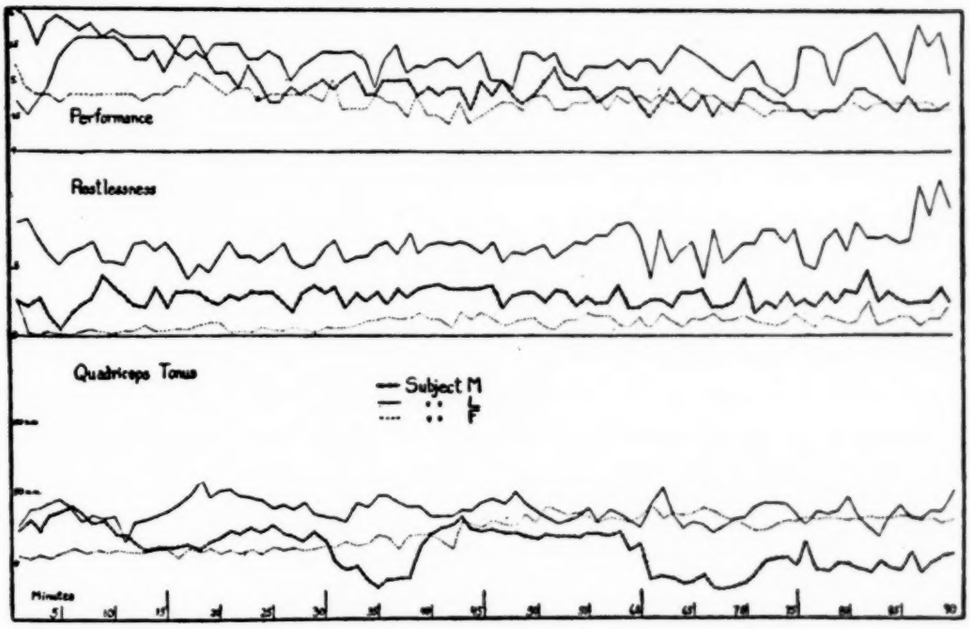

FIG. 6. Finger oscillation, Exp. II; composite performance, restlessness and tonus curves for 5 consecutive 90 min. sessions.

formance, we should not neglect the possibility that they are the result of some attempted reinforcement. Such a hypothesis is supported by earlier experimental work [17] and by certain facts in the curves under discussion. It should be noted that, coincident with the first periods of decreased tonus in the 45 min. test (*M*, 31/2 to 19 min.) (*L*, 4 to 9 min.) (*F*, 9 to 15 min.), all subjects were reporting the experiment pleasantly boring. However, as fatigue of the finger was felt, they tended to become more attentive to the task. Increased efforts to hold the weight in position were reported by all. These reports seem to correlate with the marked increases in

[17] Certain aspects of the relation are discussed by G. L. Freeman, Changes in tonus during completed and interrupted mental work, *J. Gen. Psychol.* (in press).

tonus present during the latter parts of the test. (*M*—15 to 40 min, *L*—25 to 45 min., *F*—15 to 30 min.)

Subject *L*'s second period of extensive tonus decline in the 45 min. test (18–25 min.) coincides exactly with the time when the load was off his finger. When questioned about this period, *L* said that the task 'had seemed to be getting easier' and that he 'guessed he sort of forgot and dozed off.' Some time afterward the sound of clicks and the pull on the finger brought him out of this state of dimming consciousness 'with

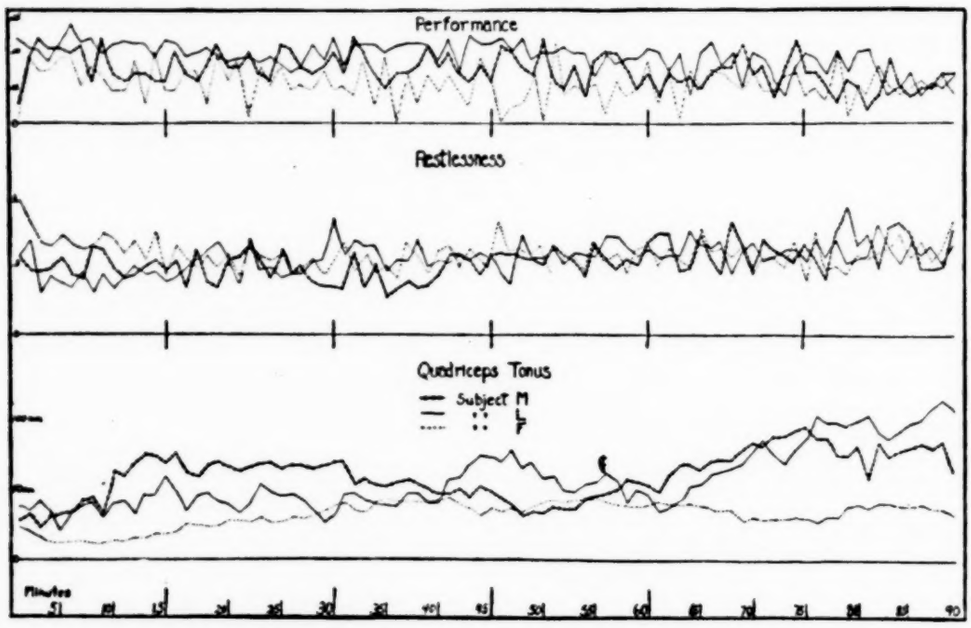

FIG. 7. Addition, Exp. II; composite performance, restlessness and tonus curves for 5 consecutive 90 min. sessions.

a start.' He 'got hold of himself' again as best he could There is an immediate increase in tonus following the placing of the load and the level on tonus is generally high during the remainder of the test. The period of 'rest' is also paralleled by a decrease in the average restlessness for this subject. Thus our technical accident proves to be a useful check of the relevancy of our neuro-muscular indicators.

The Test of Finger Oscillation (*Fig. 3*).—Work-decrement is less pronounced here than it was in the case of finger renitence. This is probably due to the essential differences between the two tests. We conjecture that since finger renitence required a constant innervation, decrement was primarily conditioned

by muscular exhaustion; whereas actual muscular fatigue in finger oscillation was delayed by (1) the reciprocal activity of the neuro-muscular processes involved and (2) the moderateness of the rate initially established by the subjects (*i.e.*, there was no standard speed to maintain).

In general the curves of restlessness show an increase as performance drops off. Temporary increments are followed by periods of relative calm, as noted in the finger renitence experiment. A comparison of Figs. 2 and 3 shows that the subjects were less restless at the beginning of the finger oscillation tests than in the case of finger renitence. We conjecture that this test involved less widespread initial activity. Our subjects reported that they did not 'mind' finger oscillation as much as the other test.

In the tonus records of Fig. 3 we find again the initial increase and decline and the subsequent series of more extensive changes. It will be further noted that there is a tendency for tonus to increase during the last few minutes of the 45 min. performance. Since our subjects were informed when 'only five min. more' remained till the end of the task, it is possible that these increases (*F* and *M*—40–45 min., *L*—25–30 min.) may be associated with the well known phenomenon of end-spurt.

One should not neglect the possibility that too great tension acts as an inhibitor. While this question yet remains for experimental examination, we can point out suggestive instances in Fig. 3. There are marked decrements in *M*'s work where tension is highest (28th min.) of 45 min. period and 5th min. of the 15 min. period); and in the 15 min. period *M*'s output improves slightly as a more moderate tension is achieved. Also *L*'s score on the 15 min. test improves under decreased tension.

The Tests of Mental Addition (*Fig. 4*).—The work analysis for the addition tests was made as nearly analogous to those of the other performances as practicable. But there is one important difference. Since the subject signalled at the completion of every 4th column only, the number of signals is less than the number of 30 sec. time units. Hence we are

forced to exhibit a dispersion diagram rather than a continuous curve. The signals of each subject are placed on the time ordinate during which they occurred and are easily distinguishable. The accuracy of the addition is indicated by the height of the signal from the base line. We have computed each subject's score at 5 min. intervals. These scores indicate the number of columns right and are obtained by counting the number of signals within the given interval and multiplying each signal by the number of columns reported which were right. A glance at the scores and the diagram shows that there is little tendency toward decrement. Subject *L* shows the only consistent decrement during his 15 min. test. Such output scores as these taken by themselves do not constitute evidence of unimpaired efficiency.

The records of restlessness indicate the relative fatigue of the addition performance. The tendency toward increased uneasiness with time is evident in spite of the masking effect which the writing movements presumptively exerted on the restlessness recorder. While it is not clear from the averages given in the curves, inspection of the actual records showed that the majority of temporary increases in postural change paralleled the subjects' undertaking of a new group of addition columns. It seems extremely doubtful if such behavior actually facilitated the performance. The gradual increase is more likely an index of the diminishing effectiveness of the directive set.

Simple inspection shows that the tonus accompaniments of mental addition were not nearly so extensive as they were in the case of the other two performances. The most obvious explanation would be that less reinforcement is required to maintain a pace. In this connection it is significant to note that increments of tonus are greatest during the 45 min. test (*F* and *M*, 15 to 40 min.) when 'interest' is likely to lapse and consequent voluntary effort become necessary.

Relation of the Neuro-Muscular Indices to the Period of Work.—Bills and Brown [18] report a close relationship between efficiency (output), tension (pressure on a pencil) and the

[18] A. G. Bills and C. Brown, The quantitative set, *J. Exper. Psychol.*, 1929, 12, 301–323.

amount of work set for the subject to do. Since the subjects in our own experiments were only set to work for a given length of *time*, the results are not directly comparable. Nevertheless, our data bear upon questions similar to those discussed by these authors, as follows:

(1) Table I shows that initial output is not greatly influenced by the *time* the subject expects to work. This agrees with Bills' conclusions. The only positive relation between initial output and period of work is found in the case of the addition tests.

TABLE I

THE AVERAGE OUTPUT PER SEC. (FOR FIRST 5 MIN.) OF THREE LENGTHS OF WORK PERIODS

Task	5 Min. Period	15 Min. Period	45 Min. Period
Finger renitence	.034	.112	.044
Finger oscillation	5.19	4.91	5.21
Addition	.047	.046	.034

(2) Table II indicates that initial restlessness is influenced by the period of work-expectancy. This table gives the subjects' average restlessness per sec. for the first 5 min. of work on the several tasks. The numbers in parentheses in the 15 and 45 min. columns give the average restlessness of the entire work period whereas those outside give only the average

TABLE II

AVERAGE INITIAL (5 MIN.) RESTLESSNESS FOR THREE PERIODS OF WORK

Task	5 Min. Period	15 Min. Period	45 Min. Period
Finger renitence	.233	.218 (.386)	.196 (.346)
Finger oscillation	.690	.609 (.636)	.306 (.426)
Addition	.480	.484 (.463)	.378 (.466)
Averages	.488	.433	.293

for the first five minutes. The reader will note that while initial restlessness decreases as the period of work-expectancy is lengthened, average restlessness for the longer periods of work almost equals that of the 5 min. task (addition) and may even exceed it (finger renitence). This is apparently due to the tendency for restlessness to increase as the subject becomes fatigued.

(3) Bills' study also suggested that the phenomenon of initial-spurt was related to muscular tension, the shortest task being accompanied by the greatest increment. Although his method of recording tension is open to serious question, the relation deserves careful attention. In the curves of quadriceps tonus we have seen little evidence of either general increment or decrement. Table III shows, however, the tendency

TABLE III

AVERAGE INITIAL (5 MIN.) TENSION FOR THREE PERIODS OF WORK

Task	5 Min. Period	15 Min. Period	45 Min. Period
Finger renitence	39.33	36.33	37.66
Finger oscillation	26.	11.66	24.
Addition	24.	3.33	24.33
Average	29.44	20.44	28.66

for the highest recorded reading of initial tension to occur with the 5 min. tasks. This is in accord with Bills' second experiment and contrary to the results of his first. Our data cannot be considered decisive because (1) the difference between the 5 and 45 min. tasks is so slight and (2) it is very doubtful if these readings were all reckoned from the same 'relaxation' baseline.

(4) More significant is the average tonus (mm per sec.) for the first five min. of all tasks. In Table IV we see a very

TABLE IV

THE MEAN TONUS (MM PER SEC.) FOR FIRST 5 MIN. OF THREE LENGTHS OF WORK PERIOD

Task	5 Min. Period	15 Min. Period	45 Min. Period
Finger renitence	24.74	23.60	19.96
Finger oscillation	39.23	20.23	14.60
Addition	20.91	1.15	10.61
Averages	28.29	14.99	14.72

definite tendency for tonus to be highest with the 5 min. tasks. This may mean, as suggested by Bills, that the reinforcement derived from the musculature lessens the apparent work decrement by offsetting the onset of fatigue. But it is not

clear that the relation shown in the table below is always facilitative. For example, in the tests of finger oscillation, both *M* and *L* gave lower performance scores for the 5 min. task than for the first 5 min. of the 45 min. task. Yet the initial changes of both these subjects are more extensive for the short period task. Of course, this may be a case of where too great tension becomes an inhibitor.

(5) *Variability.*—A survey of the charts of Exp. I indicates that variability in performance, restlessness and tonus increases with time. In Fig. 8 we give the mean variations of the records obtained in the 45 min. tests. The three upper curves in the upper section of the chart show the composite variability scores for each of the three performances. The middle group of curves shows the composite variability in the subject's restlessness during each test. The lower group of curves shows the composite variability in the tonus records. These M.V.'s were obtained as follows: (1) The work period was divided into 9—5 min. units. (2) Each individual's M.V. (per 30 sec.) was computed in each 5 min. unit and for each type of record. (3) The individual scores were averaged. By obtaining the deviation from the mean of each 5 min. unit instead of from the general average, the relative variability of different units are made comparable. Connecting the scores of the 9 units makes an artificial means of presentation. The use of bar diagrams would be more satisfactory were it not for the problem of superposition.

Figure 8 shows that variability in performance, restlessness and tonus is usually greatest near the end of 45 min. tasks The exceptions are (1) the restlessness scores for addition and (2) the tonus scores for finger oscillation.

There is some probability that high initial variability is a consequence of poorly systematized initial performance and that increased variability toward the end of the task depends upon the processes of relative fatigue. The base-ball pitcher 'warms up' so that a stable integration of pertinent neuro-muscular processes may be available when he starts the game. The same picture is presented in the genetic account of writing, —the child's general writhing and use of large muscle groups

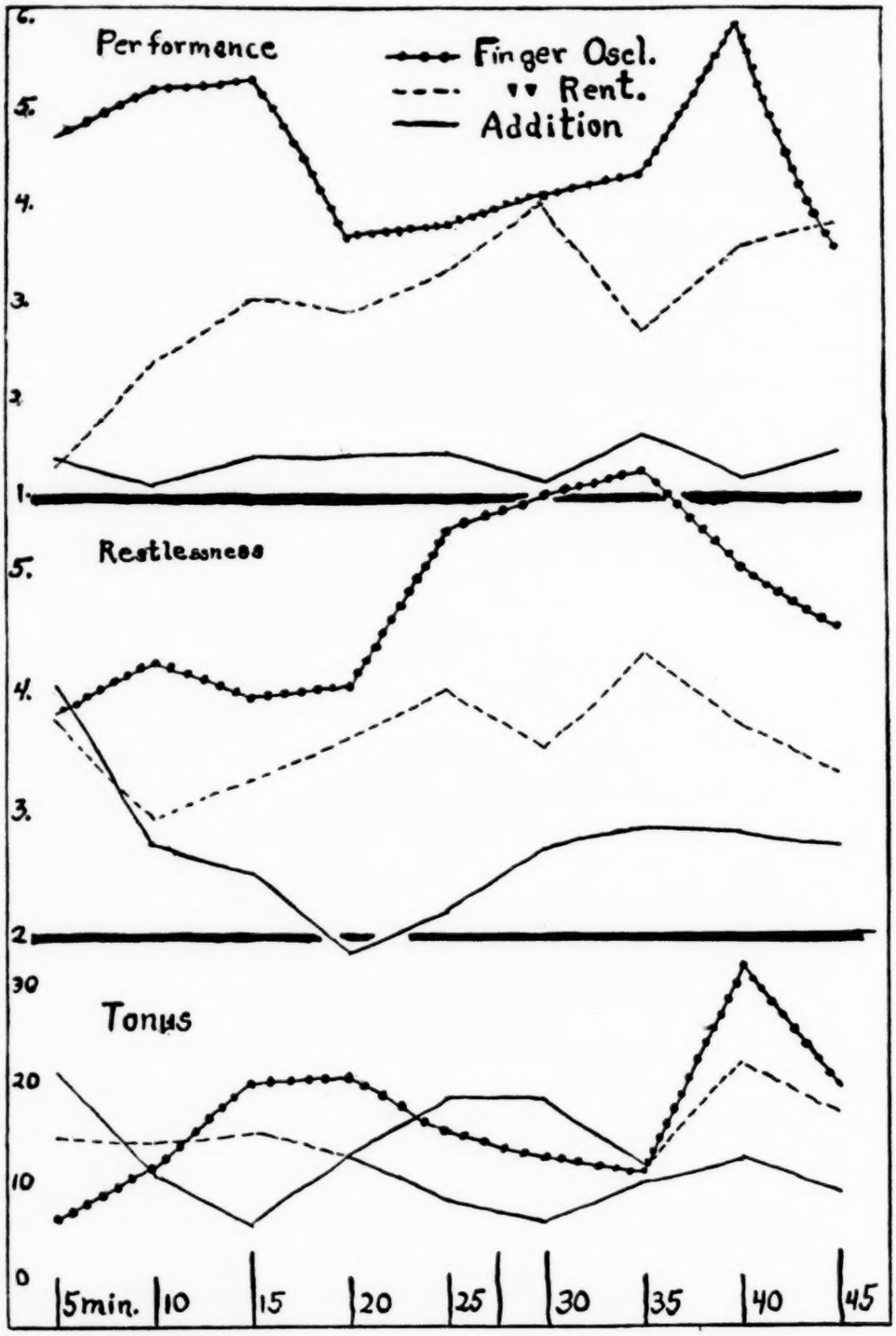

FIG. 8. Relative variability in performance, restlessness and tonus during the 45 min. tests (Exp. I), by 5 min. segments.

being gradually replaced by finely adjusted finger movements. In the development of finger oscillation, Dodge and Bott [19] found that co-contraction of antagonistic muscle groups preceded the stable pattern of innervation. On the other side, Dodge [20] has shown that the variability in fatigued eye movement depends upon errors in coördination.

Thus the completely adapted and unfatigued performance might be expected to show a relatively stable pattern of response. The dominance of this pattern in the behavior flux presumptively involves the active inhibition of many other mechanisms. Relative fatigue in any part of the dominant integration, however, would disturb the balance of this organization. Variability in performance and in the involved neuro-muscular processes is a natural consequence.

It is probable that the performances of some of our subjects were initiated when systematization was relatively poor. The influence of such cases upon the general averages may explain the fact that initial variability sometimes exceeds all other scores. We conjecture that the continuous use of a completely systematized performance would show consistently increased variability with time. Our results cannot be taken as decisive in this matter. They should be considered simply as indicating the desirability for further research in the conditions of variability.

Individual Differences in the Curves.—Little individual difference is apparent in the form of the output curves; 48 percent show a general decrement. *F*'s curves are the most characteristic in this respect (55 percent).

Greater differences in performance are found by comparing the amount of work done by the subjects. The averages are given in Table VI.

It will be seen from a glance at the above scores that *L* excelled both of the other subjects in all tests. *L* was apparently the type of individual who naturally works at top speed. He may be characterized as tense, nervous, hyperexcitable, aggressive, and probably emotionally unstable.

[19] R. Dodge and E. A. Bott, Antagonistic muscle action in voluntary flexion and extension, *Psychol. Rev.*, 1927, **34**, 241–272.

[20] R. Dodge, The laws of relative fatigue, *Psychol. Rev.*, 1927, **24**, 106–108.

TABLE VI

INDIVIDUAL DIFFERENCES IN WORK-OUTPUT (EXP. I)

Subjects	Time	Scores (Ave. per Sec.)		
		Ave. Lapses in F. Ren.	Ave no. F. Oscl.	Ave. Correct Add. Columns
L	5 min. test	.006	5.07	.053
	15 min. test	.319	5.13	.044
	45 min. test	.293	4.83	.042
M	5 min. test	.013	4.84	.043
	15 min. test	.144	5.55	.046
	45 min. test	.328	4.07	.028
F	5 min. test	.083	5.05	.046
	15 min. test	.385	4.62	.035
	45 min. test	.305	4.78	.033

M, on the other hand was usually calm and collected. It is probable that he was not greatly interested in the experiments and that he tried to avoid fatigue as much as feasible. Naturally, however, his pride would not let him slump too far. We conjecture that he tried hardest on the finger oscillation tests; but although he appeared somewhat exhausted he would never admit fatigue. Subject *F* represents the phlegmatic, methodical individual, of regular habits. Although a habitually slow worker his interest and conscientiousness were very real.

In Table VII we see objective evidence that *L* was the

TABLE VII

INDIVIDUAL DIFFERENCES IN AVE. RESTLESSNESS (PER SEC.) EXP. I

Test	Time	Average Restlessness for		
		L	M	F
F. R.	5 min.	.2	.23	.27
	15 min.	.5	.31	.35
	45 min.	.35	.17	.52
F. O.	5 min.	1.4	.41	.16
	15 min.	1.35	.36	.21
	45 min.	.63	.39	.26
Addition	5 min.	.41	.48	.55
	15 min.	.36	.5	.53
	45 min.	.58	.4	.42
Average...		.642	.361	.363

most restless of the subjects. It is also evident from this table that restlessness is a function of the type of performance tested as well as a characteristic of the worker.

The tonus curves indicate the greatest of individual differences. *M*'s tendency toward a gradual increase of tonus with time may be contrasted with the marked decreases of subject *L*. *F*'s tonus changes are less extensive than those of the other two subjects. Table VIII shows that *M*'s

TABLE VIII

INDIVIDUAL DIFFERENCES IN MEAN TONUS (PER SEC.), EXP. I

Test	Time	Subjects		
		M	L	F
F. R.	5 min.	8.45	72.23	−6.
	15 min.	61.32	35.82	36.06
	45 min.	37.16	30.72	32.4
F. O.	5 min.	40.9	77.01	−.2
	15 min.	55.96	−22.21	.12
	45 min.	39.94	−10.66	−35.10
Addition	5 min.	9.93	69.60	−16.80
	15 min.	14.81	−33.42	−19.32
	45 min.	31.89	−9.95	64.08
Averages	5 min.	19.76	72.94	−7.66
	15 min.	44.03	−6.58	5.62
	45 min.	36.33	17.11	20.46

working tonus always exceeded that of his pre-working state. That *L*'s and *F*'s records do not show the same condition may be partly an artifact. We know that it was impossible to get anything like a 'relaxation' baseline for *L*'s tonus records during Exp. I, and the fallacious zero position has resulted in the assignment of minus values to many parts of his tonus curve.

Available evidence seems to indicate that the pattern of the tonus-changes accompanying mental work depend upon the way in which the subject adapts to the performance. *M* and *L* can be contrasted in this respect. While we had no absolute measure of how relaxed these subjects actually were prior to a test, certain facts support the view that *L* was much more tense than was *M*. Usually we found *L*'s quadri-

ceps tension increasing from the moment the apparatus was placed on the tendon. It was not until the second experiment that he began to show signs of better pre-experimental adaptation. He no longer appeared bothered and restive as the apparatus was placed and his tonus record during this period more nearly approximated the characteristics of a relaxed state. High initial tension is probably a consequence of wide-spread neural activity. A consideration of *L*'s curves of decreasing tonus in connection with this hypothesis suggests the possibility that the decrement results from either (1) early fatigue of the mechanisms of neuro-muscular reinforcement or (2) the elimination of unnecessary reinforcing agents present during the initial unadapted phase of the performance.

Results (Exp. II)

The data obtained in our second group of experiments are summarized in the form of composite curves (Figs. 5, 6, 7). These curves show the average (per sec.) scores in performance, restlessness and tonus for 5 periods of 90 min. each.

1. *The Test of 90 Min. Finger Renitence* (*Fig. 5*).—Performance shows both marked decrement and variability. The subjects' composite curves are somewhat representative of their daily records. The form of *M*'s curve calls for special comment since it is typical of two of *L*'s daily curves, three of *M*'s and one of *F*'s. We conjecture that such periods of marked recovery following early decrement are the results of some additional reinforcement. The increased tonus of subjects *M* and *L* during the latter part of these tests indicates that such reinforcement may be derived from the musculature. Particularly significant is the correspondence between high tonus and low decrement (in the case of *L*) and low tonus and high decrement (in the case of *F*). This correspondence is characteristic of Exp. II. Increased restlessness with time is noticeable in the middle group of curves. Averaging has reduced the original extensity of such changes. Initial restlessness is relatively high for two subjects. All the curves show the tendency for variability to increase with the duration of work.

2. *The Test of Finger Oscillation* (*Fig. 6*).—As was anticipated by Exp. I, decrement in performance is much less marked than in the finger renitence tests. The reader will note some evidence of a warming-up process in both this and the addition performance (Fig. 7). The fact that tonus increases slightly during the first three or four minutes suggests its possible connection with this process. The restlessness curves show the characteristic features of (1) hightened initial activity and (2) increasing uneasiness and variability during the latter parts of the tests. The tonus-curves show the greatest increments late in the experimental hour.

3. *The Tests of Continuous Addition* (*Fig. 7*).—There are few new features in this group of curves. While the addition scores show little decrement, the increased variability of performance, the increase in restlessness and tonus give evidence of fatigue and voluntary reinforcement. With the examination of this last chart we are in a position to discuss the modification which apparently occurred in the subjects' tonus changes during the second group of experiments. It will be recalled that in Exp. I *L*'s tonus usually declined during the work period and that *M*'s usually increased. The more extensive data of Exp. II makes it evident that such differences are not individual characteristics. Of the total fifteen curves, only three of *L*'s showed a general decrement, five of *F*'s showed decrement and only two of *M*'s. One probable reason for the increased number of rising curves was suggested in Exp. I; the subjects later came to show better initial-adaptation. Their pre-working state more nearly approximated relaxation and there was less widespread activity incidental to beginning the task.

4. *The Daily Averages.*—Table IX shows each subject's average (per sec.) performance, restlessness and tonus score on each day of work. The three tests are arranged in the order in which the subjects performed them. An asterisk in any column indicates some known deviation from the usual psychophysical condition. The assumption is that such deviation may have influenced the score.

In the table one finds substantial evidence of progressive

TABLE IX

DAILY AVERAGES (PER SEC.) PERFORMANCE, RESTLESSNESS AND TONUS SCORES (EXP. II)

Tasks	Day	Subject M			Subject L			Subject F		
		Perf.	Rest.	Tonus	Perf.	Rest.	Tonus	Perf.	Rest.	Tonus
Continuous addition	1st day	.047	.408	91.3	.032	.263	48.2	.022	.315	91.8
	2d day	.028	.280	38.5	.039	.276	−27.2	.029	.256	−11.4
	3d day	.051	.153	191.8	.033	.283	51.7	.031	.356	49.1
	4th day	.044	.339	−76.2	.033*	.339*	151.6*	.028	.319	6.6
	5th day	.058	.171	61.2	.038	.118	57.9	.031	.139	22.3
	Ave...	.046	.270	61.3	.035	.256	56.4	.028	.277	31.7
Finger renitence	1st day	.070	.121	−32.7	.03	.162	77.2	.094	.176	45.6
	2d day	.196	.132	20.1	.02	.270	36.7	.001	.050	−37.5
	3d day	.073	.263	25.9	.018	.325	78.6	.025	.051	−6.5
	4th day	.023*	.244*	74.0*	.002	.278	80.2	.000	.107	69.5
	5th day	.041	.118	−29.	.002*	.290*	105.5*	.025	.130	−29.6
	Ave...	.081	.176	11.7	.016	.245	75.6	.029	.103	8.3
Finger oscillation	1st day	5.03	.297	−58.8	4.98	.833	35.	4.31	.097	29.9
	2d day	4.98	.338	3.9	5.05	.597	28.8	4.66	.099	156.
	3d day	5.08	.257	29.1	5.35	.627	42.5	4.91	.107	−27.6
	4th day	5.36	.232	74.8	5.32	.474	55.6	4.83*	.057*	−86.9*
	5th day	5.02	.211	−6.2	5.63	.601	36.4	4.86	.049	8.9
	Ave...	5.09	.267	8.6	5.26	.626	39.6	4.71	.082	16.1

adaptation. Performance improves in most cases. (The reader will recall that improvement in finger renitence is evidenced by a decreasing number of lapses in finger oscillation by the increase in oscillations and in continuous addition by increase in column rightly solved.) Restlessness is less on the fifth than on the first day of a task. Comparison of the daily scores reveals a number of ambiguous cases. The average restlessness for the first group of tests given (addition) is greater than for the second and third groups. Of course, this may be partly due to essential differences in the performances. It will be recalled that such differences were found in Exp. I (using counter-balanced practice order).

The effect of adaptation (or practice) on the daily tonus changes is not entirely clear. The differences between the total averages is significant and there is some evidence of decline on the succeeding days of each test series. But factors such as psycho-physiological condition and attitude are com-

plicating circumstances. Suggestive instances of the operation of these factors are found on *M*'s 4th day at finger renitence and his 1st day at continuous addition, and *F*'s 4th day at finger oscillation. In the case of *M*, we see unusually high tonus and performance scores. These are probably the result of the mild euphoria which *M* reported to follow his attendance at a late dance the night before. On *L*'s 4th day at addition, extreme fatigue was reported as due to extended preparation for a final examination. The experimenter's observations of *L*'s behavior on this day indicates that he had to make an extreme effort to carry out the experiment. The same is true of his 5th day at finger renitence. On both these days *L* was in the state of hyper-excitability which characteristically proceeds a serious breakdown. *F*'s 4th day at finger oscillation shows the effects of a sluggish condition which was reported to follow exhaustion in an athletic event and the inevitable alcoholic accompaniment.

Discussion

Only the most tentative physiological interpretation can be given our results. We have found increased restlessness and tonus as the normal accompaniments of both task initiation and extended exercise of the performance. The initial increments may be understood as a consequence of (1) lack of control of the directive set over the behavior flux and (2) widespread neural activity required to develop a creditable performance (warming-up process). The suggestion may also be made that the second group of factors is a consequence of the first; that is, the increased neural activity serves to reinforce the potency of the directive set in its competition with other reaction-tendencies. The later and more extensive increments in restlessness and tonus are apparently related to these same factors. Long continued activity is thus characterized by the relative loss in dominance of the directive set and by an increase in neuro-muscular reinforcement necessary to balance the competition of stronger and incompatable tendencies.

In the latter part of the tests work decrement was *greatest*

where restlessness was most pronounced and *least* where the tonus increments were most extensive. Those subjects who showed the least work decrement had the highest average tonus and there was also a marked tendency for restlessness to be greatest where work decrement was most rapid. Thus it seems probable that restlessness is more indicative of loss of control and tonus more indicative of attempted reinforcement.

The connection between restlessness and lack of control is fairly clear. Two of the main features of disturbance in a well adapted act are (1) the presence of unnecessary and accessory movements and (2) variability in the neural organization. Both of these features are suggested in our records of restlessness. Not only was there an increase in the number of slight postural shifts but also their variability increased with time. The running commentary of our subjects indicated that the majority of such movements were incidental to the performance. Such reports as 'looking at the time,' 'annoyed with the arm-straps,' 'thinking of exam I must take next hour,' etc., frequently accompanied temporary increments in restlessness. From such reports we may tentatively conclude that increased restlessness shows the prominence in the behavior flux of tendencies other than the directive set.

The use of tonus as an indicator of neuro-muscular reinforcement is more open to question. In the first place, the significance of our tonus increments is complicated by two little-known factors: (1) the absolute tension of the quadriceps muscle prior to recording and (2) the relation which the recorded changes bear to the total pattern of muscular response. In the second place, the relation between tonus and the level of total reactivity is as yet obscure. To be physiologically significant reinforcement should be discussed in terms of energy-transformation rather than in terms of 'stimuli' and 'reactions' which facilitate. We are aided in our attempt to factor the reinforcement equation by the high correlation recently found to exist between tonus and degree of effort.[21] Assuming that this correlation was operative in the experiments herein discussed, we have mainly to consider the rela-

[21]These results will be included in a forthcoming monograph by the senior author.

tion of the quadriceps response to the total pattern of neuro-muscular activity.

At first glance our report of increased tonus seems to be contradictory to results of several earlier researches. The most accurate of these measurements was made by Dodge [22] on the pulse rate. The work of Travis [23] and Golla [24] on tonus was carried out with less refined instruments than our own. Dodge found that the pulse rate was *less* during the last half of an examination period than the first. His argument that the greatest amount of neuro-muscular activity occurs early in a test rests on the correlation obtaining between pulse-rate and metabolism. The correlation between tonus and metabolic rate has not been precisely demonstrated as yet. But the difference between his results and our own need not be due to relative merits of correlation. The writer's [25] earlier experiments with performances similar to those used by Dodge showed the greatest increments in tonus at the beginning of the tasks; and it is conceivable that the performances used in this research were accompanied by an increasing pulse rate. It must be remembered that taking an examination involves a somewhat different type of adjustment than does monotonous work. The questions are first surveyed as a total and the attack organized. It would be much more difficult as well as unnuatural to conceive the temporal exigencies of finger renitence at the beginning of an extended work period. Of course, as Dodge pointed out, the question of whether there is increment or decrement in energy-transformation depends upon the accurate placing of a baseline. In the present experiments this was not possible because we lacked an instrument which measured the absolute tension of the muscle. But while the zero position in successive records did not represent the same stage of relaxation, it is probable that the major aberrations have been cancelled in the composite curves.

[22] R. Dodge, Mental work, *Psychol. Rev.*, 1913, **20**, 1–42.

[23] R. C. Travis, A study in the measurement of muscle tonus and its relation to fatigue, *J. Exper. Psychol.*, 1924, **7**, 201–212.

[24] F. L. Golla and S. Antonovitch, The relationship of muscular tonus and the patellar reflex to mental work, *J. Ment. Sci.*, 1929, **75**, 234–241.

[25] G. L. Freeman, *loc. cit.*

The difference between our results and those of Travis and Golla is apparently due to the time and period when the records were taken. Travis reports that tonus is *less* following extended muscular activity. In order to check this observation, one of the authors (F) climbed flights of stairs for 15 minutes. Tonus readings were taken both before and after the activity. If the terminal reading was taken quickly, heightened tonus was sometimes shown. The more usual picture, however, caught the organism in the 'exhaustion' phase (lowered tonus). The records in the present experiment also showed a drop at the termination of work. It thus seems probable that cessation of any act involving heightened neuro-muscular activity is usually accompanied by a period of relative exhaustion. During this time neural activity approaches and frequently falls below the pre-working level. The latter case is most likely to occur when the pre-work baseline is established at the crest of an 'anticipatory' increase. We have already mentioned this possibility in connection with our own experiments. We expect that it applies with equal force to the results of Travis.

In like manner we can agree with Golla that greatest increments in tonus occur early in a record. *But for short tests only*, where relative fatigue is not a factor favoring reinforcement While Golla does not state either the exact length of his tasks or their nature, he implies that they were of but short duration. So far as we know, ours are the first continuous records of tonus taken over an extended period of time (90 min.).

Since the question of possible reinforcement is so important to any study of continuous work, we may be guided by two neuristic principles. The first of these proposes that while reinforcement may be derived from the activity of any part of the neuro-muscular system, the pattern will vary presumably with the performance under survey. For example, continuous writing is more likely to involve the increased activity of arm rather than leg muscles. The second principle suggests that the focus or center of reinforcing activity will shift with time from muscles immediately concerned in the task to more remotely related groups.

We chose to record from the quadriceps for purely technical considerations. This muscle has, at best, a very minor place in the pattern which normally accompanies the allotted tasks. But while it is not the focal part of these patterns, it probably does reflect the amount of activity in such foci. It is likewise conceivable that the foci of activity shifted during the extended work period; that is, due to relative fatigue of available mechanisms, the neural patterns changed qualitatively. Thus many of our tonus-increments might simply be the results of a shift of reinforcing activity to the quadriceps group. We are of the opinion, however, that averaging the daily scores has notably reduced any such qualitative effects and that our composite curves are indicative of real quantitative changes.

But does the increase in neural activity always work to compensate for the apparent work decrement? In his study of mirror drawing, Snoddy [26] found that accumulated repetition brought into play more and more arm musculature with a consequent loss of coördination. He ascribes this effect to 'irradiation.' Instances of increased activity serving to inhibit performance were found in our own records. Such results only show how variable is the line between facilitation and inhibition. Whether a given activity will reinforce or inhibit depends especially upon the neuro-muscular pattern with which it becomes incorporated. Reinforcement appears to be chiefly non-conscious or automatic. The commentary of our subjects show very few 'conscious' or voluntary attempts to reinforce by contraction of any part of the musculature. The experimenters, however, frequently noted significant behavior such as clenching the teeth, doubling the fist and biting the lip. These gave some indication of correlating with tonus-increments.

Under continuous exercise, the pattern of the organism's activity shows two apparent forms of diminished returns. The first type of dimunition presents the picture of decrement in work-output with a constant degree of effort. The opposed type shows a constancy of work-output with an increasing

[26] G. S. Snoddy, An experimental analysis of a case of trial and error learning in the human subject, *Psychol. Monog.*, 1920, **20**, 124.

degree of effort. In an experimental situation such as out own, where the subject is highly motivated and his performance susceptible to relative fatigue, we should expect these two tendencies to neutralize each other somewhat. But the individual records show the second tendency to be more in evidence. This agrees with the work of Morgan [27] and Freeman [28] on overcoming resistances. Both of these investigators have reported that the organism usually increases the amount of effort expended in an attempt to keep the level of work output constant.

Our results vividly recall the fallacy of studying fatigue in units of work output alone. In view of the present availability of indicators, the failure to measure some aspect of general reactivity during extended work is both unnecessary and unwarranted. At least some simple indicator, such as breathing, postural change or eyelid reaction can be employed by all. While the utilization of such behavior will not reveal reinforcement directly, increments in either amount of variability of reaction will show relative loss of control. Wherever it is feasible, however, some direct indicator of energy-transformation such as pulse, tonus or oxygen consumption should be used. The routine inclusion of at least one measure of organic activity during work is sure to result in a more competent and thorough analysis of the conditions effecting the performance scores.

Summary

The experiments were designed to measure changes in restlessness and tonus which accompany protracted activity. The experimental tasks were (1) finger renitence, (2) finger oscillation and (3) addition of four place numbers. In the first group of experiments, subjects performed the tasks for periods of 5, 15 and 45 minutes. The results indicate that the initial level of both restlessness and tonus is related to the period of work. Variability in performance, restlessness and tonus increases with the duration of work. High variability

[27] J. J. B. Morgan, The overcoming of distraction and other resistances, *Arch. of Psychol.*, 1916, **35**, 84 pp.

[28] G. L. Freeman, *loc. cit.*

and increased neuro-muscular activity characterize the initiation of poorly adapted performance.

In the second and more extensive group of experiments, each of the three experimental tasks was carried over a period of 5 consecutive 90 min. sessions. The results showed increased tonus and restlessness as the normal accompaniments of continuous work. In the latter part of these tests decrement was least where tonus was highest and greatest where restlessness was the more pronounced.

The authors relate their results to the laws of relative fatigue. The consequences of protracted activity are (1) relative loss of control of the directive set over the behavior flux and (2) reinforcement probably active to balance the competition of incompatible reaction tendencies. Restlessness is suggested as more indicative of the first set of factors and tonus as more indicative of the latter. The importance of reinforcement is stressed and two heuristic principles are discussed. In view of its importance and the availability of indicators, the authors urge the inclusion of some measure of the spread of neuro-muscular activity as a routine part of every fatigue experiment.

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THE ROLE OF MUSCULAR TENSIONS IN STYLUS MAZE LEARNING[1]

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INTRODUCTION

It is the aim of this study to investigate the role of muscular tensions in stylus maze learning. This aim embraces an investigation of the problem from three angles: first, a study of the effect of the complexity of the problem, the degree of mastery, and related phenomena upon muscular tensions as normally expressed by the subjects; second, a study of the relation of muscular tensions to the speed of learning; third, a study of the effect of artificially inducing such tensions upon the speed of learning. It is a common observation that a tensing of certain muscle groups occurs in preparation for and during important and vigorous experiences of many kinds ranging all the way from colorful emotion to ordinary experiences such as climbing a flight of stairs hurriedly. In a dental chair one may catch himself pushing against the foot rest or gripping the arms of the chair with great force during a crucial part of the experience. During examinations one may observe students massaging their hands and fingers made numb from gripping their pencils or even observe the tension of facial muscles. Bills (1) has shown that such concomitant muscular tension serve a beneficial purpose in memorizing and in doing mental work. His investigation centered upon the effect of voluntarily induced muscular tensions upon these mental processes. The present study extends the investigation to problem situations such as that presented in the maze and to two other aspects of the general problem, namely, the effect of the difficulty of the problem, progress in learning, etc.,

[1] From the psychological laboratory of the University of Chicago.

The writer gratefully acknowledges the assistance of Professor A. G. Bills in every phase of this research.

upon the natural expression of muscular tensions and the relation of such tensions to the speed of learning. It does not necessarily follow that because induced tension facilitates rote memorizing and mental work it would also facilitate learning of the type involved in the stylus maze problem, or that it would facilitate it to the same degree. This investigation is also concerned, then, with the study of the role of muscular tensions in motor learning, as contrasted with ideational learning such as memorizing.

Another factor which led to the selection of the maze as the learning material for this study was the fact that it seemed possible to construct a stylus which would give a serviceable measure of muscle tension of the subjects while solving the problem. Furthermore it seemed possible to vary the difficulty of the parts of the maze so as to observe the effect of varying degrees of difficulty of the task upon the expression of muscular tension. A maze has certain other advantages for a study of this kind. It constitutes a problem whose difficulty varies from time to time, even with the same subject. The subject may become confused and 'lost' during any given trial and have considerable difficulty in getting around to the terminus. A knowledge of any changes in muscular tension which might take place during such trials would throw significant light upon the nature of the adaptive processes.

Considerable experimentation has been made, either directly or indirectly, upon the phenomena of muscular tensions in relation to mental activity.[2] Some of the studies bearing more directly upon this problem are cited below.

Bills (1) in his study raised the question of whether these concomitant motor expressions are merely an overflow phenomenon of some kind or whether they are of some value *per se* to the individual. As a result of his investigations in which he induced muscular tensions artificially he concluded that they are of value in and of themselves. He induced tension by having his subjects squeeze spring dynamometers, one in each hand. He found these exercises directly beneficial in learning nonsense syllables and paired associates, and in

[2] Bills has adequately reviewed the pertinent literature in his study cited above.

adding columns of digits and in recitation of scrambled letters. In the addition and recitation experiments he found that induced tension had the effect of lessening the work decrement. Induced tension had the effect of decreasing errors as well as increasing speed.

Miller (**11**) has shown that the experience of pain and the observable response consequent upon the receipt of electrical shocks may be diminished by 'progressive relaxation.' She had her subjects immerse the tips of their fingers in a salt solution through which an electrical current could be passed. The height of the jerk of the hand could be measured. Her subjects had had three months training in 'progressive relaxation.' Frequently one of her subjects would fall asleep in his relaxed state. The reaction of the subjects during sleep was quite similar to that during the relaxed state.

Jacobson (**6**) states that mental activity can be greatly diminished by 'progressive relaxation' and that when such relaxation is complete the subject is quite apt to fall asleep. His subjects report a dearth of mental imagery during the relaxation of the eye muscles. In another study reported by him (**7**) Jacobson seems to have obtained rather clear evidence that effort to attend is accompanied with motor tensions and that inattention and effortlessness are associated with relaxation.

The height of the knee jerk has usually been taken as a good index of muscular tension. Voluntary tensing of any of the muscles of the body increases the height of the knee jerk. Tuttle (**14**) has shown that the height of the jerk may be materially increased by arithmetic work over that of a passive attitude and that the height is greater during an ordinary period of conversation than during a passive period. Lombard (**10**) pointed out as early as 1886 that an increase in the height of the knee jerk may be effected by irritation of the skin, by voluntary movements such as swallowing, talking, and clinching of the hands, and by exciting the attention. He also pointed out that the jerk may be facilitated by cerebral activity and decreased by cerebral inactivity and sleep.

Morgan (**12**) has shown that in typewriting situations the

subjects have a tendency to strike the keys harder during distractions. Laird (**9**) has shown in an experiment with typists that the amount of expired carbon dioxide is enormously increased over the normal by introducing distractors. These experiments point to a close relationship between such physiological processes and a factor called effort.

Apparatus

The apparatus used in this experiment has been described in a note entitled Apparatus for Recording Muscular Tensions, recently accepted for publication by this *Journal.* It consists primarily in a pressure stylus with a piston device for recording downward pressure and a pneumatic attachment for recording the squeeze or horizontal pressure. Incidentally a record of jaw tension was secured by training spring tambours upon the jaw muscles. A record of the muscular tensions exerted upon the pressure apparatus was made upon a kymographic drum. In these experiments tension values are reported for downward pressure only.

Detailed Plan of the Experiment

The investigation is divided into three main parts. Part I is given over to the study of the factors which influence the expression of tension. An attempt is made to see if the degree of tension varies with the difficulty of the various parts of the maze and to see if it varies from maze to maze when such mazes are of different degrees of difficulty and to ascertain what direction the variation takes. It is the aim of this part of the study to see if tension varies with the degree of familiarity with the mazes and to see if it varies during the initial and final stages of the learning process. An attempt is also made to see if the tension expressed during the trials in which the greatest number of errors is made—trials in which the subject has the greatest difficulty, differs from that expressed during the trials in which the least number of errors is made, and to see what direction the variation takes, if any. Part II is taken up with the relation of tension to the speed of learning. The aim of this part of the study is to determine whether there

is any relation between the degree and constancy of muscle tensions as expressed naturally by the subjects and the speed with which they solve problems of the kind presented in stylus mazes, and to determine what the relation is. Part III deals with the effect of induced tension upon the speed of learning. The experiment described therein is designed to determine the effect of inducing muscle tensions artificially upon the speed of learning.

Part I. Factors Which Influence the Expression of Muscular Tensions

(*a*) *Tension in an Easy Part of a Maze Versus That in a Difficult Part.*—Easy parts (parts without cul de sacs) constitute the first and last fourths of maze CIV. An electric marker indicated upon the drum the point at which the end of the first 'easy' portion had been reached for each trial; and in a similar way it indicated the point at which the subject entered upon the final 'easy' portion in his tracing. By taking the average tension for each of the 'easy' portions and comparing this with the tension expressed during the tracing over a similar period of time in the adjacent difficult portion the effect of degrees of difficulty upon the expression of muscle tensions could be determined. Twelve graduate students in psychology were used as subjects in this experiment. The results are found in Table I.

(*b*) *Tension on an Easy Maze Versus That on a Difficult Maze.*—In this experiment the tension expressed during the mastery of an easy maze is compared with that expressed during the mastery of a difficult maze. Sixteen subjects participated in this experiment. All the subjects were undergraduates with little training in psychology. Each subject learned both mazes, 24 hours elapsing between the two tasks. A counterbalanced order was used. While mazes III and IV were not purposely selected in such a way as to fit into this experiment, it happened that considerable difference in difficulty was found between them. The tension comparisons obtained from the data for these two mazes are also included in the results. The time, trials and errors required to learn the mazes constitute the criteria of difficulty.

(*c*) *Tension on Trials with the Greatest Number of Errors Versus Tension on Trials with the Least Number of Errors.*—The average tension for the three trials with the greatest number of errors is compared with that for the three trials with the fewest errors. Only trials from the first half of each record were considered. Data gathered from the studies made with mazes CIII, CIV, and III were used in making these computations. The data from maze CII were treated in a similar way save for the fact that the average tension for the two trials out of the first six with the greatest number of errors is compared with the average tension for the two trials out of the first six with the fewest errors. From maze CIII two consecutive trials from each record were selected for comparative purposes in which there was a difference of 10 or more in errors between the two trials and in which case the trial with the fewest errors came first. The first and second pairs of trials meeting this requirement which occurred in each record were selected. The varied attack upon this problem was made in an effort to control the influence which changes in tension with progress in learning might have upon these results.

(*d*) *Changes in Tension During Progress in Learning.*—The average tension is computed for four different stages of three trials each. The first three trials, the middle three, the last three and the three immediately preceding them were chosen for this purpose. Since the criterion of learning was three consecutive correct trials it seemed that a separate tabulation of the last three trials might yield significant results. By this procedure it is possible to observe the changes in tension and variability which occur over these four stages and to study the effect of increasing familiarity with the problem upon the expression of muscular tension. The results of these computations are found in Table IV.

(*e*) *Initial Changes in Tension.*—Three different observations are made upon this problem. Comparisons are made of the average tension of each of the first three trials of mazes CII and CIII. Secondly, a study is made of the changes in tension which occur during the first minute of tracing each of

these mazes. In this part of the study tension is averaged for 10 second intervals, making it possible to make six different comparisons within the minute period. A similar study is made of the changes in tension during the first minute of four trials each for 24 subjects selected at random from all the mazes. The results are contained in Table V.

(*f*) *Final Changes in Tension.*—This phenomenon was investigated by examining all the records for three mazes, CII, CIII, and III. The tension and time values for each of the last three trials were computed. The average tension for each of the last three trials taken separately was computed and the values compared with one another. Time values are offered as an aid in interpretation. The average tension for the last three trials taken together is compared with that for the three preceding trials. (See Table IV.)

Part II. Relation of Tension (Naturally Expressed) to the Speed of Learning

The criteria of speed of learning are scores in time, trials and errors, each computed separately. No special experiments were made to test this relationship. The data obtained for all the mazes were used in making these calculations.

Part III. The Influence of Artificially Induced Tension upon the Speed of Learning

Thirty-two subjects were used in this experiment, 15 of whom were undergraduate students with no prior experience with mazes; 17 were graduate students with varying degrees of sophistication. Each subject learned two mazes, III and IV. One maze was learned by each subject under the influence of induced tension, the other was learned under normal conditions. The counterbalanced order was used both as to temporal order of the mazes and as to tension. Tension was artificially induced in this experiment by having the subjects hold a weight against a pulley while tracing the mazes. The weight exerted a static pull of 14 pounds. The subject held the weight in one hand. The cord to which the weight was attached pulled at right angles to the body and was on a level

with the maze. The subject sat erect. This procedure necessarily produced considerable tenseness in several muscle groups as well as in the hand, arm and shoulder muscles. The subject had to brace himself in order to prevent being pulled over or to one side by the weight. Hence, in order to maintain his postural attitude the subject had to tense various back and leg muscles. In order to obviate the possibility of fatigue and a consequent change in experimental attitude on the part of the subjects resulting from protracted holding of the weight they were informed that they could rest from the load between trials if they grew tired. Since the subjects differed considerably in this respect (some subjects required no rest at all) this procedure seemed preferable to rest at stated intervals. Occasional pauses were introduced in the condition in which no weight was held. This was done in order to make the two conditions somewhat comparable with respect to the condition of pauses interpolated during the learning.

The usual tension records were taken throughout this experiment. It was possible to observe the effect of induced tension not only upon the speed of learning, but also upon the tension expressed in the hand operating the stylus. It was also possible to observe the effects of induced tension upon the constancy of the tension expressed throughout the stages of the learning process. These phenomena are studied by comparing the tension data obtained for the condition of induced tension with the data obtained for normal conditions. The several effects of induced tension are recorded in Tables XI–XIII.

It seemed possible that some significance might be attached to the variability of the tension curves. Variability was computed by subtracting the length of the base line for a given trial from the total distance traversed during that trial by the pen recording tension. The measure of variability is the length of the curve minus the length of the base line. If for a given trial the length of the tension line is 15 inches and that of the base line is six inches there are nine inches of excessive distance because of the crookedness or variability of the line. The greater the difference between the length of the base line and the tension line the greater is the variability.

Results and Discussion

Part I. Factors Which Influence the Expression of Tension

(*a*) *Relation of Tension to the Difficulty of the Portions of the Maze.*—The table below gives the average vertical hand tension of all subjects and all trials for the two intervals in which all the 'cul de sacs' were blocked off and that for the two adjacent sections involving the same length of time. Maze CIV was used for this purpose.

TABLE I

Showing the Relation of Tension to the Difficulty of the Maze

Average tension for initial 'easy' section of the maze.	Average tension for adjacent difficult section of the maze.
.21 inches	.32 inches
Average tension for final 'easy' section of the maze.	
.39 inches	.32 inches

While these data are significant they fail to contribute a great deal to the purpose for which this experiment was planned. The average tension for the initial 'easy' section is significantly less than that for the subsequent difficult section. But this same phenomenon, as shown in Table VI, is present in all the records. There is a period at the beginning of each trial in which a muscular set is being assumed in which one finds just such a phenomenon as that presented above. One is not warranted in assuming that these data show any relation between tension and the difficulty of the portions of the maze. On the other hand they fail to show that there is no such relation.[3] It will also be observed from the table above that the data comparing the tension for the final 'easy' section with that of the adjacent difficult section show that the tension is significantly greater during the easy period than for a similar difficult period. It seems improbable that this represents a true relation. It seems more

[3] A more valid procedure could have been carried out by arranging the 'easy' portion in the center of the maze. Unfortunately almost a year has been consumed in working up the data from the kymographic drum records. Some problems have arisen which were not anticipated at the time the experiments were made. The experimenter does not now have access to the apparatus so that some of these suggestions can be investigated.

likely that this difference is an expression of an end-spurt phenomenon and that if there should be any changes in tension during the tracing of this section of the maze because of its easiness such changes are obscured by this phenomenon which we may call end spurt.

(*b*) *The Relation Between Tension and the Difficulty of the Maze.*—It will be recalled that mazes CII and CIII were selected specifically for this purpose. It developed that sufficient difference in difficulty obtained between mazes III and IV to warrant using their data in studying the relation between tension and the difficulty of the maze. The differences in difficulty may be seen by inspecting the time, trial, and error scores for these mazes in the following table. The same subjects learned CII and CIII, and III and IV.

TABLE II

SHOWING THE RELATION BETWEEN TENSION AND THE DIFFICULTY OF THE VARIOUS MAZES

Maze	Average Tension	Average Seconds	Average Errors	Average Trials
CII	.302 inch	354	20.7	10.3
CIII	.204 inch	2671	424	44.9
CIV	.315 inch	2043	246	26.9
IV	.335 inch	563	82	14.
III	.318 inch	1543	221	29.8

Taken at their face value these results seem to indicate that there is an inverse relation between tension and the difficulty of the task. Upon further examination of the data one finds that these differences are due entirely to the fact that there is a drop in tension on the more difficult mazes as learning progresses and that there is a rise in tension on the easy mazes with subsequent trials. This is readily seen from Table IV, where the tension values for the different mazes are averaged separately for four different stages in learning. The increase in tension with progress in learning the easier mazes may be due to a factor of spurt which the subjects exhibit when they discover they are on an easy maze. This suggestion derives experimental support from recent studies by Bills and Brown (2). They found that tension increased sig-

nificantly on the shorter 'time sets' and that the decrement was less per unit of time on the shorter 'sets' than upon the longer ones. If there is a relation between tension and the difficulty of the task, and data to be presented subsequently indicate that there may be, it is legitimate to assume that it is obscured in this experiment by changes in tension on successive trials.

The phenomenon of variability is studied in relation to several phases of this general problem. However, no very great significance is attached to this feature of the study. From the nature of the case one might expect greater variability on the difficult mazes. There are more 'cul de sacs' in the difficult mazes. The subjects had a tendency to move in strokes, as it were. One unit (one 'cul de sac' or one alley) constituted a convenient stroke. The movement spans are shorter on the difficult mazes since they have more 'cul de sacs' and are cut up into shorter units. These movement units give tension curves which have rhythmical appearance. The rhythms on the more difficult mazes are more frequent and give more variable curves.

(*c*) *Tension for Trials in Which the Greatest Number of Errors was Made Versus That for the Trials in Which the Least Number of Errors was Made.*—In the case of mazes CIII, CIV and III, the average tension on the four trials in the first half of each record with the most errors is compared with the average tension on the four trials in the same section of the records with the fewest errors. In the case of maze CII the average tension of the two trials among the first six with the greatest number of errors is compared with the average tension of the two trials among the first six with the smallest number of errors. A special treatment of the data for maze CIII is given after the maze designated CIII′. The treatment represents an attempt to control the effect of a general decrease in tension with progress in learning. The decrease in the case of this maze, the most difficult of all, is especially pronounced. In the case in question two consecutive trials were selected for comparative purposes in which there was a difference of 10 or more in errors made on the two trials and in which case the

trial with the fewest errors came first. The first and second pairs of trials meeting this requirement were chosen.

TABLE III

SHOWING THE RELATION BETWEEN TENSION ON TRIALS WITH THE GREATEST NUMBER OF ERRORS AND THAT ON TRIALS WITH THE LEAST NUMBER OF ERRORS

Maze	Category	Tension	Difference in Means	P.E. (of Diff.)
CIII	Most Er's	.208 inch	.048	± .014
CIII	Fewest Er's	.161 inch		
CIV	Most Er's	.336 inch	.038	± .036
CIV	Fewest Er's	.298 inch		
III	Most Er's	.326 inch	.038	± .021
III	Fewest Er's	.298 inch		
CII	Most Er's	.275 inch	.042	± .038
CII	Fewest Er's	.233 inch		
CIII′	Most Er's	.193 inch	.028	± .020
CIII′	Fewest Er's	.165 inch		

These data show a consistent, but not individually statistically significant positive relationship between the tension expressed per trial and the number of errors made per trial. These differences obtained are fairly large and all point in the same direction. This may be suggestive of a tendency. However, the general level of tension varied greatly from subject to subject. This factor doubtless operates to give high probable errors. It seems legitimate to assume, in the light of this tendency, that the trials which are most difficult for a subject are those in which he makes the most errors and that the trials which are the easiest for him are those in which he makes the fewest errors. If this is a valid assumption, these data indicate the possibility of a direct relationship between tension and the difficulty of the task.

(*d*) *Variations in Tension with Progress in Learning.*—Tension was computed for four samples of three trials each at four different stages in the learning process. The average tension was determined for the first three trials, the middle three, the last three and the three trials immediately preceding them. These constitute the four stages.

These figures possess considerable significance for this

TABLE IV

SHOWING CHANGES IN TENSION WITH PROGRESS IN LEARNING

Maze	Stage 1	Stage 2	Stage 3	Stage 4
CII	.268 inch	.303 inch	.355 inch	.359 inch
CIII	.260 inch	.186 inch	.230 inch	.209 inch
CIV	.338 inch	.323 inch	.307 inch	.279 inch
IV	.323 inch	.368 inch	.468 inch	.472 inch
III	.333 inch	.326 inch	.309 inch	.315 inch

general problem. In the case of the more difficult mazes, CIII, CIV and III, there is present a somewhat general decrease in tension as learning progresses. The decrease in tension on maze III is not as pronounced as that on CIII or CIV. It will be recalled that one half of the subjects learned this maze under induced tension. One of the effects of induced tension was to keep tension relatively high throughout all stages in learning. It seems reasonable to suppose that the decrease in tension on these mazes may be due in part, at least, to an increase in familiarity with the mazes. Another possible factor contributing to the decrease in tension is that of a general work decrement. In the case of maze III, on which maze the decrease in tension is greatest, the average time required to learn was 2671 seconds. The average time required to master CIV was 2043 seconds and that for III was 1543 seconds. It will be observed that the decrease in tension is somewhat proportional to the length of time required to master the mazes.

Mazes CII and IV present quite a different picture. Here, it will be observed, tension increases throughout the stages in learning. The learning times for these two mazes are extremely short when compared with that for the other three mazes. The average number of seconds required to learn maze CII was 354, and that required to learn IV was 563. The subjects never acquired as great a degree of familiarity with these two mazes as they did with the other three. In learning the more difficult mazes the subjects explored every part of them over and over again. In the easier mazes certain portions were explored rarely or not at all by many subjects. Furthermore, it seems likely (as suggested above) that the

subjects, when they discovered that they were confronted with an easy task, put forth an increased effort to terminate it as quickly as possible in order to make a good score. It will be observed that the initial tension on the easy and difficult mazes, when learned by the same subjects, is not essentially different.

(*e*) *The Phenomena of Initial Changes in Tension.*

TABLE V

SHOWING THE AVERAGE TENSION PER TRIAL FOR EACH OF THE FIRST THREE TRIALS

Maze	Trial 1	Trial 2	Trial 3
CIII	.311 inch	.248 inch	.251 inch
CII	.288 inch	.296 inch	.301 inch

There is an enormous difference in the difficulty of these two mazes, CIII being several times as difficult as CII. It seems that the differences in the direction of the initial changes in tension on these two mazes may be interpreted in the light of their difficulty. One might assume that the initial high level of tension followed by a drop, in the case of maze CIII, points to the initial spurt phenomenon and, indeed, suggests an interpretation of the initial high level of efficiency in terms of an initial high level of muscular tension. The time required for the first tracing was usually quite long. The subject may realize that he is confronted with a lengthy task and may settle down to a slower pace as it were. On the contrary, in the case of maze CII, the subject may realize from his early experience with the maze that he is confronted with an easy task and therewith increase his effort with successive trials.

TABLE VI

SHOWING THE CHANGES IN TENSION OVER SIX INTERVALS OF 10 SECONDS EACH, REPRESENTING THE FIRST MINUTE OF LEARNING TIME

Maze	Interval					
	1	2	3	4	5	6
III	·34	·43	·43	·44	·43	·39
CIII	·33	·40	·34	·32	·29	·28

Tension is given in this table in terms of hundredths of an inch. In the subsequent table a similar study is made which embraces the first minute of tracing of each of the first four trials of 24 records selected at random, save for the fact that no record was chosen for this purpose which showed no appreciable tension. This would account for the fact that the tension values are abnormally high when compared with the average of the tension of the whole of the records.

TABLE VII

SHOWING THE CHANGES IN TENSION OVER SIX INTERVALS OF 10 SECONDS EACH, REPRESENTING THE FIRST MINUTE OF LEARNING TIME ON EACH OF THE FIRST FOUR TRIALS

Trial	Interval					
	1	2	3	4	5	6
1.	.24	.28	.30	.35	.37	.36
2.	.31	.43	.50	.50	.52	.50
3.	.24	.38	.46	.52	.54	.54
4.	.26	.41	.50	.57	.55	.56

Tension is recorded in terms of hundredths of an inch. The data presented in the two preceding tables indicate that a few seconds are required in each trial for establishing a motor set.

(*f*) *The Phenomena of Final Changes in Tension.*—Tension values are averaged for each of the last three trials for all subjects on three mazes. The criterion of learning in all cases was three consecutive errorless trials. Hence the three trials considered in this connection are necessarily trials without errors. The subjects were all informed of this criterion. The average time required for tracing each of these three trials is given together with the tension values in the following table as an aid in interpreting the results.

These results show increase in tension on the last trial over the preceding trial. They seem to indicate rather convincingly that changes in tension are to be regarded, in part at least, as expressions of changes in effort. This interpretation of the results is substantiated by the corresponding time

TABLE VIII

SHOWING CHANGES IN TENSION AND TIME VALUES OVER THE LAST THREE TRIALS

Maze	Trial	Tension	Time
CII	Last but two	.333 inch	21.1 seconds
CII	Last but one	.353 inch	19.8 seconds
CII	Last	.358 inch	20.3 seconds
CIII	Last but two	.187 inch	27.9 seconds
CIII	Last but one	.194 inch	27.1 seconds
CIII	Last	.257 inch	29.7 seconds
III	Last but two	.346 inch	22.6 seconds
III	Last but one	.316 inch	22.1 seconds
III	Last	.362 inch	22.7 seconds

changes. The reader will observe by inspecting the above table that there is an increase in time required to trace the mazes on the last trial. This would indicate that the subject proceeds more cautiously—that he is making a greater effort to trace the mazes correctly. The subject is aware that making an error on this trial means that he must start over in his effort to achieve three consecutive errorless trials, which fact would add at least three trials to his score.

PART II. THE RELATION BETWEEN TENSION AND THE SPEED OF LEARNING

The records of the various subjects on all the mazes are ranked according to tension on their respective mazes. These individual records are divided into two groups on the basis of tension. The category marked *A* contains the 50 percent of the records showing the greatest degree of tension. That designated *B* contains the 50 percent of records showing the lowest degree of tension. The P.E. of the difference between the means is given for all comparisons.

All the differences for maze CII are more than three times their probable errors. On maze CIII the difference between the means for time is 2.5 times its P.E., and for errors is 4.4. times its P.E., and for trials, is about equal its P.E. It is apparent that there is a consistent and significant relation between tension and speed of learning for mazes CII and CIII. It is equally apparent that no striking or uniform tendency is present in the case of the other three mazes. As a partial

explanation of this disturbing factor the reader's attention is called to the fact that all the subjects for mazes CII and CIII were without prior experience with mazes. They were, for the most part, sophomores and juniors taking their first courses in psychology. The subjects for the other mazes

TABLE IX

SHOWING THE RELATION BETWEEN TENSION AND THE SPEED OF LEARNING

Maze	Category	Average Seconds	Average Errors	Average Trials
CII	A	222	8.3	8.5
CII	B	485 ± 76.00	33.0 ± 6.50	12.1 ± .98
CIII	A	2426	321	40.9
CIII	B	2916 ± 205.31	527 ± 46.50	48.9 ± 7.80
CIV	A	2027	265	25.7
CIV	B	2059 ± 295.64	227 ± 45.53	28.0 ± 5.40
IV	A	520	81	14.3
IV	B	606 ± 87.00	83 ± 14.75	14.1 ± 1.55
III	A	1638	244	31.9
III	B	1447 ± 207.25	197 ± 41.25	27.7 ± 3.5

constituted a more variable group, ranging all the way from advanced graduate students in psychology to undergraduates with very little training in this subject. The members of this group possessed varying degrees of maze experience. Some of the subjects were to some degree familiar with all the mazes in the laboratory; others had had a moderate amount of contact with mazes and others had had no experience with them. The reader will bear in mind that each maze group was selected for the study of a particular phenomenon such, for example, as the effect of induced tension upon the speed of learning. In such cases pairs of mazes were used. Care was taken to see that a subject had previously learned both mazes of a given pair in case he had learned one of them. It seems that this factor of variable experience might be sufficient to cut across and tend to interrupt any other tendency which one might be studying. Former experience might well be an aid in some cases and a hindrance in others. It might change the experimental attitudes of the subjects and their tension records in a complex set up such as this in various ways. A test of this assumption is possible to some extent. It happens that 15 of the 32 subjects used in mazes III and IV were without

previous contact with mazes. When the records of these 15 subjects are ranked according to tension the results are in accord with those for mazes CII and CIII as shown in Table IX above. The results of this feature are given in Table X.

TABLE X

SHOWING THE RELATION BETWEEN TENSION AND SPEED OF LEARNING FOR 15 SUBJECTS WITHOUT PRIOR EXPERIENCE

Maze	Category	Average Seconds	Average Errors	Average Trials
III	A	1102	164	29
III	B	2067 ± 306.00	312 ± 68.27	42 ± 6.20
IV	A	485	72	17.2
IV	B	630 ± 68.25	100 ± 13.01	15.6 ± 3.50

These results lend weight to the assumption made above relative to the detrimental influence of the variable factor of previous experience upon the relation between tension and the speed of learning. The final conclusion regarding this relationship must rest to a large degree upon the validity of this assumption. If the assumption is valid the conclusion would follow that there is evidence of a significant relationship between muscle tensions as measured in these experiments and the speed of learning material of this kind.

PART III. THE EFFECT OF INDUCED TENSION

In this part of the study the results of the various observations upon the influence of induced tension are given. The reader will recall that tension was induced artificially by having the subjects hold a weight with a static pull of 14 pounds against a pulley. In all these calculations the results in category *A* represent those in which the subjects were under the influence of induced tension. In category *B* the results are given for normal conditions.

TABLE XI

SHOWING THE INFLUENCE OF ARTIFICIALLY INDUCED TENSION UPON THE TENSION EXPRESSED UPON THE KYMOGRAPHIC DRUM

Maze	Category	Average Tension
III	A	.369 inches
III	B	.268 inches ± .043
IV	A	.364 inches
IV	B	.306 inches ± .044

These results show that artificially induced tension has a tendency to increase the expression of tension on the kymographic drum. This fact would seem to suggest that increasing the tension in one or more muscle groups tends to increase the tension in all other groups. This is in agreement with the fact that there is a significant positive correlation between the various indices of muscular tension employed in this study. It is also in accord with the well-known fact that induced tension in any muscle groups of the body heightens the knee jerk.

TABLE XII

SHOWING THE EFFECT OF ARTIFICIALLY INDUCED TENSION UPON THE CONSTANCY OF TENSION EXPRESSED ON THE DRUM THROUGHOUT THE STAGES OF LEARNING

Maze	Category [4]	Stage 1	Stage 2	Stage 3	Stage 4
III	A. Tension in inches	.347	.390	.378	.405
III	B. Tension in inches	.319	.262	.240	.225
IV	A. Tension in inches	.421	.472	.481	.494
IV	B. Tension in inches	.225	.264	.375	.454

[4] In category *A* are found the tension values for the condition of induced tension; in *B* those are found for the condition in which tension is not artificially induced.

These results show that induced tension has the effect of stabilizing the motor attitude of the subjects during the learning process. They also show that induced tension has the effect of producing relatively high initial tension and that this initial high level of tension is not only maintained throughout the four stages of learning studied but that the level of tension increases regularly from stage to stage. The results for maze III present a particularly interesting picture in this connection. It will be observed that for the condition without induced tension the tension values decrease from beginning to end, as indeed they do on all the longer mazes in which tension is not artificially induced. On this same maze, however, it will be observed that tension increases regularly to the end of the learning period when induced tension is used. As noted earlier, tension on mazes CII and IV, short easy mazes, increases regularly from beginning to end under all conditions. In maze IV of the table above it is interesting to observe the extremely high initial tension for the condition with induced

tension, as compared with that for the condition without induced tension.

These facts seem to tie up with some of the earlier findings. For example, if we were correct in interpreting the expression of increasing tension on the two easy mazes as indicative of increasing effort, then it would seem that the effects of induced tension could be interpreted, in part at least, as producing an effect equivalent to increased effort. Indeed these findings may be interpreted as throwing light upon the nature of effort. In the light of this interpretation muscular tensions would be regarded as one of the important components of effort.

TABLE XIII

SHOWING THE EFFECT OF INDUCED TENSION UPON THE RATE OF LEARNING

Maze	Category	Average Seconds	Average Errors	Average Trials
III	A	1133	158	25.8
III	B	1954 ± 207.84	286 ± 40.62	34.3 ± 4.12
IV	A	469	68	14.3
IV	B	657 ± 83.07	94 ± 15.00	14.1 ± 4.30

In the case of maze III the mean difference between the two conditions, tension and normal, for time is approximately four times the probable error, for errors is three times the probable error, and for trials is approximately twice the probable error. The benefits resulting from tension are less marked on maze IV. The differences are about twice their probable errors for time and errors. Practically no difference exists in the case of trials. The difference in the degree to which the data for these two mazes reveal benefits from induced tension possesses considerable significance for this general problem. Inspection of Table XI reveals that the increase in tension, as expressed on the drum, because of induced tension, was little more than half as much in the case of maze IV as in the case of maze III. It was pointed out earlier that there is a marked tendency for tension to increase on mazes IV and CII, the easy mazes, with successive trials. This was interpreted as meaning that the subjects put forth and increased effort when they discovered that they were

confronted with a task likely to be terminated in a reasonably short time. As mentioned earlier, this interpretation seems to have experimental justification. In the light of the differences to which these mazes show benefits of induced tension it is suggested that there is a possibility that induced tension is more efficacious on longer than on shorter tasks.

Hunter and his students, for example Heron (5), have shown that maze scores are only moderately reliable. In view of this fact these results are strongly suggestive of genuine facilitation of learning by induced tension. Apparently there may be several factors which influence the speed of learning. Some of these have been insufficiently studied. Doubtless subjects differ in the amount and kind of imagery used, in tendencies to verbalize, in the size of the muscle groups employed in tracing the mazes, in tendencies to retrace, methods of exploration, perseverative tendencies, and in many other ways. These factors, when uncontrolled, as was the case in these experiments, may contribute to unreliability. In view of these possibilities it seems rather significant that the speed of learning mazes can be influenced in a manner even moderately significant statistically by the introduction of a single factor, muscular tension. Despite the fact that all the results obtained in this study are not statistically significant considerably importance may be attached to the fact that practically all the results point in the same direction and that they compose with the main body of facts derived in this study.

It is difficult to see how mere chance selection could give these results. A fairly large number of subjects was employed (32). Each subject learned both mazes, one under induced tension, the other under normal conditions. The obtained results show that the same subjects who learned one of the mazes most quickly under the influence of induced tension were the subjects who proved to be the poorest learners on the other maze under normal conditions.

The objection may be offered that muscle tensions, as induced in this experiment, are of no very great service *per se;* but that on the contrary the increased efficiency comes from a

redoubled effort to overcome the effects of distraction or to terminate the task made disagreeable by holding the weight. Several objections may be offered to this point of view. In Bills' study, cited above, the same subjects worked under the same conditions for a number of days. He suggests that if the advantage of muscular tension were due merely to the distracting influence of the method of inducing the tension the subjects ought to become habituated to the distracting influence of the inducing agent and cease to show benefits from it. On the contrary he found that the beneficial influence increased with practice. It seems likely that overcoming distracting influences by increasing effort is a similar thing to the condition involved in increasing muscular tension. Morgan (**12**) has shown that the process of overcoming distraction is accompanied by increased muscle tension. That these muscle tensions serve a useful purpose is suggested by the fact that the results of the present study indicate that there is a positive relation between the expression of these tensions and the speed of learning. The data presented in part I of this study, relative to initial spurt, end spurt, and the relation of tension to the length and difficulty of the task, seem to indicate that there exists an essential relationship between muscular tensions and effort. Bills and Brown (**2**) in their studies on the influence of 'quantitative set' found the decrement significantly less on the smaller 'amount sets' than on the larger ones, amount set being determined by a knowledge on the part of the subject of amount of work to be done. Not only was the decrement less for the shorter sets, but also muscular tension increased significantly during the performance of the shorter tasks. These results are supported by the findings presented in part I of this study relative to the high level and constant increase of tension on the two short mazes as opposed to a lower level and a decrease of tension on the longer mazes. On the bases of these considerations the suggestion is offered that increases in muscular tensions have an effect equivalent to increases in effort.

In these experiments few subjects showed any signs of strain from holding the weight. Only two stated that the

weight seemed to distract or bother them. The subjects usually stated that they 'ignored' or 'forgot about' the weight while tracing the mazes.

Relation Between the Three Indices of Muscle Tension

The following table shows the correlation, first, between downward pressure and horizontal pressure or grip, second, between downward pressure and jaw tension, and third, between horizontal pressure and jaw tension. The correlations were computed between the respective tension values for 300 trials selected at random.

TABLE XIV

Showing the Relation Between Three Measures of Muscle Tension

First Variable	Second Variable	Correlation
Downward pressure	Horizontal pressure	r .67 ± .02
Downward pressure	Jaw tension	r .44 ± .03
Horizontal pressure	Jaw tension	r .33 ± .03

The correlation between downward and horizontal pressure seems rather high in the light of the apparent unreliability of the measure of horizontal pressure. It is difficult to form a judgment as to what extent this correlation represents a genuine relation between the tension of two muscle groups. It is doubtless influenced to some extent by the fact that it would be necessary to grip the stylus to some extent in order to exert downward pressure upon it. On the other hand one might expect to find considerable correlation between two expressions of tension of muscles involved in the same act and involving to some extent the same muscles. It will be observed that the correlations are much lower, but significant, between downward and horizontal pressure and jaw tension. This difference may be due, in part at least, to a greater relation between the tension of muscle groups involved directly in the performance of an act than between that of muscle groups not so involved. It may well be that muscle tension is greater in general among muscles active in the performance of a certain act than among those not directly involved in the act. Even though muscle tension was present in the jaw muscles every time it was present in the muscles involved in

manipulating the stylus it would not necessarily follow that such tension would express itself by pressing the teeth together. The subject might well extend his jaw or twist it to one side, which fact would hardly be recorded on the drum. If the subjects had been given something to bite upon or hold between their teeth probably better results would have been obtained from this feature.

General Summary

1. There seems to be a consistent positive relation between tension and the difficulty of the task. The chief source of evidence for this statement is derived from the fact that tension on the trials with the greatest number of errors is greater than that on the trials with the fewest errors. The differences are consistent in that they all point in the same direction, although most of them are not statistically significant.

2. Significant changes in tension occur with progress in learning.

(*a*) Tension decreases somewhat regularly with successive trials on the longer and more difficult mazes. The decrease is directly proportional to the length of time required to learn the mazes.

(*b*) Tension increases with successive trials on the easy mazes. These results signify a relation between muscular tension and mental set.

(*c*) Tension for the last trial is greater, on an average, than that for the preceding trial. The time required to trace the last trial is greater than that on the preceding trial. These concomitant phenomena are interpreted to mean an increased effort to trace the last trial correctly (three consecutive correct trials constituted the criterion of learning). These findings are regarded as throwing light upon the phenomenon of end spurt.

3. There is considerable evidence that a positive relation obtains between tension and the speed of learning. The results for the subjects naïve with respect to maze learning point unmistakably toward this conclusion. The results for the sophisticated subjects show no consistent tendency.

4. The tension in the hand operating the stylus is increased by the artificially induced tension in the other hand. Inducing tension artificially has the effect of producing relatively high initial tension and enhancing the tension throughout the stages in learning; whereas tension under normal conditions decreases on all the longer mazes during progress in learning.

5. The rate of learning is materially affected in a positive way by artificially inducing muscular tensions. The improvement obtains in five of the six comparisons.

6. On the basis of a fairly consistent interplay of phenomena revealed by the foregoing experiments the conclusion is drawn that there is an increase in muscular tensions during effortful activity and that these tensions are valuable in activity of the kind involved in learning mazes.

Interpretation

The foregoing results seem to be best interpreted in the light of the phenomenon of 'facilitation.' Several examples of this phenomenon are found in psychological literature as well as in everyday observation. Simple demonstrations can be had by holding the breath for a relatively long period and observing the increasing tenseness of various muscle groups. Similar observations may be made from exerting maximum squeeze upon a dynamometer, or from maintaining the arm in an extended horizontal position to the point that it requires extreme exertion. These 'extra' muscular tensions seem to be of assistance in executing effortful acts of this kind. Bills has aptly applied the term 'remote controls' to this phenomenon. In the experimental literature one meets the fact that reflex activity is enhanced by inducing tension in muscles not directly involved in the performance of the act. Miller has shown, as cited earlier, that the liveliness of a sensory experience resulting from electrical stimulation, as well as the motor response thereto, is greatly diminished by 'progressive relaxation.' Fere (**4**) has demonstrated that muscular contractions are concomitants of attentive processes. It has been well demonstrated, particularly by Todd (**13**), that reaction time to two sensory stimuli is quicker than that to either

one alone and that to three quicker than that to two. The most adequate neurological explanation of this psychological phenomenon seems to be that of 'facilitation' by summation of nervous impulses having different sensory origins. By means of a final common path stimuli arising from different receptors may produce a single response which may, because of the summation of impulses, be quickened and strengthened —'facilitated.' The suggestion is made that in this same sense the impulses arising from sense organs lodged in muscles and tendons, owing to stimulation by muscular contractions, may re-enforce the impulses aroused by the dominant stimulus and aid in the production of the response.

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THE INFLUENCE OF A CHANGE OF CONDITIONS UPON THE AMOUNT RECALLED[1]

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The general purpose of these experiments was to investigate the extent to which the performance of an act is dependent upon the conditions that obtained when that act was learned. The specific problem was to determine the extent to which recall is dependent upon the conditions that prevailed at the time the material was memorized. The general plan of the experiment was to have the subjects memorize under certain specified conditions and to test their ability to recall twenty-four hours later when the same conditions prevailed or when those conditions had been changed in definite, prearranged ways. Changes in three typical conditions were arbitrarily selected for study: (1) changes in the sensory situation; specifically, in the kinæsthetic factors, as brought about by alterations in posture at the time of recall; (2) changes in the sensory mode of presenting the stimulus words; and (3) changes in the form of the response at recall.

Most of the experimental literature relates to the first topic, *i.e.*, the relationship of the learned response to the broader sensory situation in which it occurs. Darrow (4) studied the effect of posture on the free association process. He found that certain attitudes tended to facilitate while others inhibited the process insofar as they were congruous or incongruous with the train of thought. Bills (1) experimented with kinæsthetic factors in his study of the influence of muscular tension on the efficiency of mental work. He found that more was accomplished in the periods of muscular tension than during relaxation. The effect of a change of these conditions at the time of recall was not determined, however. Wong and Brown (17) have shown that the more

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complicated mental activities required in the solution of the Yerkes Multiple Choice problems are facilitated or inhibited by the condition of the room in which the work is done. Twelve subjects working in an unkept, unattractive attic room made more wrong responses and solved fewer problems than the dozen working in an attractive, artistically arranged study.

Pan (**12**) made an extensive study of the dependence of learning and recall upon the immediate environmental situation in which the material is presented, the situation in this case referring to the visual context or background in which the material appeared. Pairs of words and words and pictures were to be associated. The context was composed of numbers, words (related or unrelated to the material to be memorized) and picture post cards, on which the paired words were printed. The writer concludes (p. 490) that "the recall of material is favored by the presence of an environmental factor which has some associative connection with that material and in the absence of such an association the environmental situation is likely to be unfavorable to recall." Oberschelp (**11**) studied the influence of context on recall under varying degrees of learning in an attempt to add further interpretation to the findings of Pan. Lists of 25 pairs of words were presented visually to the 20 subjects either 3, 6, 9, or 14 times at one sitting. No recall was attempted until twenty-four hours later. No relation was found to exist between the number of trials and the strength of the association between the words and their contexts. Smith and Guthrie (**15**) report an unpublished experiment on the effect of a change in the sensory situation on recall by W. R. Wilson. A saving of 11.4 percent in repetitions was effected when the relearning of the nonsense syllables was attempted in the same environment—outdoors or in the laboratory—in which it was learned. It was found that 9.4 percent in repetitions was saved when the odor of peppermint present at the learning was also present during the relearning. Ten subjects participated; lists of 10 nonsense syllables were used as memory material.

In the field of animal behavior the work of many experi-

menters is à propos. The attempts to isolate the various sensory cues employed by animals in learning have established the importance of the total sensory environment in causing the smooth functioning of the act. Watson (**16**), while demonstrating the value of kinæsthetic cues in the maze problem with the white rat, observed that a change in the maze environment brought about by rotating the maze resulted in a disturbance of the habit. Experiments on rotation of the maze by Porter (**14**) with sparrows; by Hunter (**7**) with pigeons; and by Yoakum (**18**) with squirrels, show that the maze habits of each of these groups are dependent to some extent on the sensory setting in which the learning takes place.

Carr (**2**) in a series of systematic studies with normal, blind, and anosmic rats describes the influence of changes in various conditions operating at the time of learning. For example, changing the position of the experimenter; covering or uncovering the maze after it had been learned; changing the amount of illumination; altering the space relations of the environment by rotating the maze: all had a detrimental effect on the maze habit. The conclusion is drawn, therefore, (p. 271) that "the sensori-motor act cannot be regarded as an isolated, independent function; the act was learned within a wider sensory environment and it never ceases to be wholly free from these conditions." To this extent, "the stability of the environment furthers the development of the act and conditions the regularity and accuracy of its functioning after it has become automatic."

Patrick and Anderson (**13**) support Carr's conclusions in their study of incidental stimuli and maze learning. Two groups of rats were used in this experiment. One group learned under changing conditions, with certain incidental stimuli, *e.g.*, the position of the experimenter, the location of lights and shadows and the direction of an auditory stimulus, varying from trial to trial. The second group was confronted with a constant, unchanging situation in respect to these stimuli until learning had been effected. A shift of the incidental stimuli subsequently in a recall test produced no dis-

integrative effects on the response of the first group while the group which had become accustomed to the constant conditions was markedly disturbed, in terms of the time and error scores. The writers conclude (p. 306) that "the white rat learns not the maze pattern alone, as such, but this pattern as it is related to the other stimuli acting constantly along with the maze pattern at the time."

Gengerelli (**5**) studied the effect of maze rotation on the performance of hooded rats. He observed that no deleterious effects were apparent in terms of the time score of the animals. Results with two types of mazes revealed the same trend of the data. We venture the suggestion, however, that the extreme simplicity of the mazes and overlearning were the influential factors in producing the negative results. It should be noted that 30 and 35 preliminary trials were allowed with the two mazes, respectively.

Part I. Change of Postural Conditions

In the first experiment an attempt was made to contrast the familiar, habitual situation of being comfortably seated before a study table, with a less familiar, more awkward, standing posture. The supposition was that a change of posture would be detrimental to recall, regardless of the advantages which might accrue to the one or the other as a condition of learning. Half of the subjects learning while seated were seated for the recall test; the other half stood for the recall. Half of those standing during learning stood for the recall test; the others were seated during recall. The different conditions under which learning and recall took place are set forth in the following outline:

Experiment I.—Change of postural conditions, in which the subject is,

a. seated during learning; seated during recall;
b. seated during learning; standing during recall;
c. standing during learning; standing during recall;
d. standing during learning; seated during recall.

The material memorized by these subjects consisted of lists of 16 short, unrelated, meaningful words which were

presented in serial order until each could be anticipated immediately upon presentation of the preceding word. Five lists were used in rotation with each of the four groups. The words were put together in such a way that adjacent words did not contain the same letters. Words built around each of five vowels were used an equal number of times in each list. Quarter-inch, black gummed letters formed the words in the center of uniform, white 4″ by 6″ cards. During learning the cards were stacked against a light wooden rack made for the purpose and turned by the experimenter at the rate of one every three seconds. Recall was attempted on alternate presentations to the point of one perfect recitation, *i.e.*, until each word could be anticipated accurately within the three seconds. A stop-watch was used in timing the presentations. The cards were presented only once at the recall test twenty-four hours later and the number of words correctly anticipated during this presentation constituted the recall score. The number of trials required and the words given correctly—both during the learning and at the delayed recall test—were recorded for each subject.

This experiment was conducted at Southern Methodist University during the school year 1929–30 over a period of about two months. The subjects were drawn from the classes in the Department of Philosophy and Psychology at that institution. Learning scores were obtained from 90 students; complete records—of learning and recall after the interval—were procured from 78 of these. The writer served as experimenter.

Each subject upon beginning the experiment was provided with typewritten instructions. When he had read them over he was seated in what was designed to be a natural, comfortable position before a table, in the typical attitude of study (Groups I*a* and I*b*) while the lists of words were presented to him. In assuming the posture at the table the subject was asked to sit squarely before the table, resting his arms on its surface. If standing, he was told to stand as though he were going to deliver a formal address, with arms by his side and feet together. From time to time throughout the test he was

reminded to stand (or sit) 'just as you were at first,' but after every fifth trial he was allowed to relax in his chair or to sit down, if he had been standing, for a rest period of one minute. This precaution against fatigue was taken when it became evident that otherwise many subjects would be standing or at attention almost an hour at a time in learning the words. Nothing was said, of course, about a possible change of position for the recall test twenty-four hours later and as the four groups involving posture changes were filled simultaneously, the possibility of anticipating the nature of the change was precluded to some extent, at least.

The results of the first experiment are given in Table 1. The average number of trials required for the learning and the average number of words correctly anticipated at the delayed recall test are given. The scores of the 78 students completing both parts of the test form the basis of the calculations.

TABLE I

MEANS AND σ's OF LEARNING AND RECALL SCORES FOR FOUR POSTURAL CONDITIONS

Condition (learning)	No.	Mean (trials)	σ (dis.)	Condition (recall)	Mean (words)	σ (dis.)
a. Seated	20	14.95	6.136	Seated	12.55	2.037
b. Seated	16	16.88	6.254	Standing	12.50	2.093
c. Standing	20	16.45	7.845	Standing	12.75	2.278
d. Standing	22	17.50	8.569	Seated	12.55	2.610

These figures indicate that the differences in recall scores under the four types of postural conditions are quite small; a computation of the standard error of the differences showed that they are unreliable. We must conclude, therefore, that a change in the posture of the learner did not affect his recall score.

Since these findings were at variance with out expectations, based on the results of some preliminary tests, we have sought an explanation in terms of the conditions under which the present tests were given. Three interpretations seem plausible: (1) It is conceivable that in spite of precautions the tests caused some discussion among the prospective subjects and hence some pre-adjustment to the changed conditions of the experiment. To what extent the forewarned were the fore-

armed is a matter of speculation. (2) The difficulty of the material may have been a factor. The fact that 20 words were used in the preliminary tests instead of 16 leads us to this hypothesis. The failure of Wong and Brown, *opus cite*, to obtain positive results with simpler mental problems lends further support to this supposition. (3) It seems possible that in specifying the postures too rigidly, the 'easy, natural' posture desired was not obtained; and that instead of contrasting an habitual with a novel situation we were dealing with two more or less novel conditions of tension. Therefore, while the posture was changed, the configuration or total situation confronting the subject remained the same. We regard this suggestion as the most likely.

There is some evidence of a difference in the number of trials required to learn the words under the two postural conditions. The difference between the means and the reliability of the difference in terms of its standard error are given in Table II.

TABLE II

MEANS, DIFFERENCE AND RELIABILITY OF DIFFERENCE BETWEEN LEARNING SCORES OF TWO GROUPS: SEATED AND STANDING

Condition	No.	Mean (trials)	σ (dis.)	σ (av.)	σ (diff.)	D/σ (diff.)
Seated	43	15.535	5.266	.803		
Standing	47	17.021	8.042	1.173	1.421	1.046
	(D = 1.486)					

The seated posture was, therefore, slightly more favorable to learning than the standing.

PART II. CHANGE OF SENSORY MODE OF PRESENTING THE STIMULUS WORDS

In the second experiment the variable factor was the method of presenting the material to be memorized. The different conditions under which learning and recall took place are set forth in the following outline:

Experiment II.—Change of sensory mode of presenting the stimulus words, in which there is,

a. visual presentation during learning; visual at recall;
b. visual presentation during learning; auditory at recall;
c. auditory presentation at learning; auditory at recall;
d. auditory presentation at learning; visual at recall.

Thus, half of the subjects received the material visually, and half, auditorially, during the learning period. Half of them recalled the words under the condition prevailing at learning (Groups II*a* and II*c*) while the other half (Groups II*b* and II*d*) recalled under changed conditions so far as the method of stimulation was concerned.

The conditions of this experiment necessitated a change in the memory material. Consequently, lists of 10 paired associates were constructed, each pair being made up of a short meaningful word and a nonsense syllable. During learning the first word of the pair was always presented simultaneously with the nonsense syllable, visually or auditorially. In recall tests the stimulus word was shown or spoken and the nonsense syllable was spelled out, orally. Five lists of the paired associates were used in rotation with each of the four groups.

The material here, too, was presented by means of 4″ by 6″ cards, the words or syllables being typed in the center of the cards. Three packs of cards were used in these tests: one, in which the two words of the pair were typed for visual presentation during learning; one, in which only the stimulus words appeared, for testing recall with visual presentation of the stimulus; and one in which only the nonsense syllable (response word) appeared, for use during the learning period when the stimulus item was presented auditorially. During the learning of the material and when needed in the recall test (visual presentation) the cards were propped in front of the subject by means of the afore-mentioned rack and turned by the experimenter at the rate of one every three seconds. At the outset of the learning period the pairs were presented twice before recall was attempted; thereafter, a recall test was made after every presentation of the list. The serial order of the pairs was kept constant during presentation for learning but the experimenter was careful to shuffle the stimulus items each time before testing recall. In this way

the words of the pair were associated with each other and not merely with a certain position in the series. Learning was prolonged to the point of one perfect recitation and accomplishment was measured in terms of the number of trials required. At the recall test twenty-four hours later the stimulus words were presented only once and the recall score was the number of syllables spelled out correctly within the allotted time.

The tests in this experiment were completed by 119 subjects. Fifty-six students in the Department of Philosophy and Psychology at Southern Methodist University comprise Groups II*a* and II*b*. Groups II*c* and II*d* were made up of 36 students from the latter University and 27 from the University of Chicago (Summer Term, 1930), the students of the two schools being divided almost equally between the two groups.

Typewritten instructions were furnished the subjects at

TABLE III

MEANS AND σ'S OF LEARNING AND RECALL SCORES IN GROUPS REPRESENTING CHANGES IN MODE OF STIMULATION

Condition (learning)	No.	Mean	σ (dis.)	Condition (recall)	Mean	σ (dis.)
1. (S. M. U. Subjects)						
a. Visual	28	11.18	5.289	Visual	7.50	1.476
b. Visual	28	11.46	5.660	Auditory	6.71	1.411
2. (S. M. U. Subjects)						
c. Auditory	18	9.22	3.661	Auditory	8.06	1.308
d. Auditory	18	7.72	3.870	Visual	6.50	2.114
3. (Chicago Subjects)						
c. Auditory	14	10.64	4.966	Auditory	7.50	1.998
d. Auditory	13	12.23	7.433	Visual	7.08	1.857
4. (S. M. U. and Chicago Subjects—Combined Scores of Sections 2 and 3)						
c. Auditory	32	9.84	4.573	Auditory	7.81	1.664
d. Auditory	31	9.61	6.246	Visual	6.74	2.032

the beginning of each test. In Groups II*c* and II*d* the subject was told to get the word that he heard connected with the syllable that he saw. The response word only was then shown while the meaningful, stimulus word was spoken by the experimenter simultaneously with the turning of the card.

The accomplishment of each of these groups in terms of mean scores in learning and recall is shown in Table III.

On the basis of these figures we conclude that the change in method of presenting the stimulus words was detrimental to recall both when the measurements were made with Texas and with Chicago students as subjects. In considering the performance of all subjects in the four groups we find that 7.9 percent fewer words were recalled when visual presentation was changed to auditory at the time of recall; 10.7 percent fewer, when auditory presentation was changed to visual.

The differences in mean recall scores and the reliability of these differences are given in Table IV. The differences are quite significant in terms of our standard of reliability.

TABLE IV

DIFFERENCES AND RELIABILITY OF DIFFERENCES IN RECALL SCORES IN GROUPS REPRESENTING CHANGES IN MODE OF STIMULATION

Condition (recall)	Diff. in Means	σ (av.)	σ (diff.)	D/σ (diff.)
a. Visual		.279		
b. Auditory	.79	.267	.386	2.036
c. Auditory		.294		
d. Visual	1.07	.365	.469	2.284

The median recall scores for the four groups of subjects are given in Table V. They, too, are higher when the conditions are kept constant.

The influence of the changed conditions is further observed in a study of the differences in the distribution of scores under the two conditions. Table VI affords the comparison.

It is evident that the larger percentage of high scores occurs in the groups working under constant conditions of recall. Thus, 28.56 percent of the 'visual to visual' group missed no more than one of the ten words; only 10.71 percent of the

TABLE V

MEDIAN RECALL SCORES IN GROUPS REPRESENTING CHANGES IN METHOD OF PRESENTATION OF STIMULUS

Condition	No.	Median
a. Visual to visual	28	8.00
b. Visual to auditory	28	7.00
c. Auditory to auditory	32	8.63
d. Auditory to visual	31	7.31

'visual to auditory' group did as well. Approximately 41. percent of the 'auditory to auditory' group recalled as many as nine of the words; 22.61 percent of the 'auditory to visual' group achieved that score.

Some evidence of a difference in the efficacy of the two sensory methods of presenting stimuli is offered in a comparison of the learning scores under the two conditions. Only

TABLE VI

DISTRIBUTION OF RECALL SCORES UNDER CONSTANT AND CHANGED CONDITIONS OF STIMULATION

Constant Conditions (visual to visual)			Changed Conditions (visual to auditory)		
Recall	No.	Percent of Group	Recall	No.	Percent of Group
4	1	3.57	4	2	7.14
5	2	7.14	5	2	7.14
6	3	10.71	6	10	35.70
7	8	28.56	7	6	21.42
8	6	21.42	8	5	17.85
9	6	21.42	9	2	7.14
10	2	7.14	10	1	3.57
	28	99.96		28	99.96
(auditory to auditory)			(auditory to visual)		
1	0	—	1	1	3.23
2	0	—	2	0	—
3	1	3.13	3	0	—
4	0	—	4	3	9.69
5	3	9.39	5	4	12.92
6	2	6.26	6	5	16.15
7	5	15.65	7	8	25.84
8	8	25.00	8	3	9.69
9	9	28.17	9	4	12.92
10	4	12.52	10	3	9.69
	32	100.12		31	100.13

the scores of the Southern Methodist students are discussed in the comparison of methods. Table VII gives the average scores of 85 students receiving the material visually while responding orally (Groups II*a*, II*b*, and III*b*, to be described later in connection with the next experiment) compared with those of the 36 S. M. U. students receiving the material auditorially (while responding orally) in the learning period.

TABLE VII

DIFFERENCES AND RELIABILITY OF DIFFERENCES IN LEARNING SCORES WITH VISUAL AND WITH AUDITORY PRESENTATION

Condition	No.	Mean	σ (dis.)	σ (av.)
Visual stimulation.....	85	11.094	5.986	.649
Auditory stimulation.....	36	8.472	3.841	.640
	Diff. = 2.622		σ(diff.) = .912.	
			D/σ (diff.) = 2.876	

The auditory method is shown to be decidedly the better so far as the Texas students are concerned. These results are in accord with the findings of certain experimenters, Henmon (**6**) for one, while not entirely in agreement with others. Koch (**8**) for example, finds the auditory method uniformly inferior to the visual or visual-auditory combination methods but we believe that the differences in technique may account for the discrepancy in results.

The set-up of our experiment in which a study of recall was the primary objective does not afford an authoritative interpretation of the relatively poor learning scores of the Chicago group—all of whom worked under conditions of auditory stimulation. The establishment of a reliable difference between the students of the two schools would presumably lend support to the contention of certain other writers, notably Carr (**3**) p. 230, that the superiority of either method must be explained partly, at least, in terms of differences in past training and interests of the subjects. We assume, in accepting this explanation, that the lecture method (auditory presentation of material) is typical of the undergraduate courses while the library method (visual presentation) characterizes the graduate work.

Part III. Change in the Form of the Response at the Time of Recall

The third of our experiments was concerned with changes in the form of the response at the recall test. The different conditions of learning and recall are given in the following outline:

Experiment III.—Change in form of response during recall, in which there is,

a. oral response during learning; oral recall;
b. oral response during learning; written recall;
c. written response during learning; written recall;
d. written response during learning; oral recall.

The lists of paired associates employed in the second experiment were used here. The instructions were modified slightly to make them suitable for Groups III*c* and III*d*. It may be seen that Group III*a* is identical with Group II*a* both as to conditions and as to subjects participating. It represents a control group in which the conditions of stimulation (visual) and the conditions of response (oral) remained constant for the recall tests. In the learning tests of Groups III*c* and III*d*, and in the delayed recall tests of III*b* and III*c*, the subjects were provided with cards on which spaces numbered from 1 to 10 were arranged. The subjects wrote the response syllables on these cards whenever recall was to be tested other than orally. It should be noted that both in the immediate and in the delayed recall tests subjects were asked to cover the words as they wrote them. In this way the situation was made more analogous to the one obtaining when the response was oral.

Two presentations were allowed, as formerly, before recall was tested; thereafter, recitation alternated with presentation of the series during the learning period.

Groups III*a* and III*b*, 28 and 29 subjects, respectively, were tested at Southern Methodist University; Groups III*c* and III*d*, 24 and 26 subjects, respectively, were tested at the University of Chicago. One-hundred-seven complete records are thus involved in this experiment, including the 28 duplicates of III*a*.

The results of this experiment in terms of mean scores appear in Table VIII. It may be observed that the scores of the four groups are almost identical, showing no effect of the conditions imposed.

TABLE VIII

MEANS AND σ's OF LEARNING AND RECALL SCORES IN GROUPS REPRESENTING CHANGES IN THE FORM OF RESPONSE

Condition (learning)	No.	Mean	σ (dis.)	Condition (recall)	Mean	σ (dis.)
a. Oral response.....	28	11.18	5.289	Oral response....	7.50	1.476
b. Oral response.....	29	10.66	6.834	Writ. response...	7.28	1.556
c. Written.....	26	10.27	5.842	Written.....	7.31	2.088
d. Written.....	24	10.13	4.936	Oral.....	7.50	1.682

A computation of the standard errors revealed no significant differences between the four groups. However, the distribution of scores, given in Table IX, affords evidence

TABLE IX

DISTRIBUTION OF RECALL SCORES UNDER CONSTANT AND CHANGED CONDITIONS AS TO THE FORM OF THE RESPONSE AT RECALL

Constant Conditions (oral to oral)			Changed Conditions (oral to written)		
Recall	No.	Percent of Group	Recall	No.	Percent of Group
3	0	—	3	1	3.45
4	1	3.57	4	1	3.45
5	2	7.14	5	2	6.90
6	3	10.71	6	3	10.35
7	8	28.56	7	5	17.25
8	6	21.42	8	14	48.30
9	6	21.42	9	1	3.45
10	2	7.14	10	2	6.90
	28	99.96		29	100.05
(written to written)			(written to oral)		
4	4	15.40	4	2	8.34
5	3	11.55	5	2	8.34
6	3	11.55	6	2	8.34
7	2	7.70	7	3	12.51
8	2	7.70	8	8	33.33
9	9	34.64	9	5	20.85
10	3	11.55	10	2	8.34
	26	100.09		24	100.04

unfavorable to the changed conditions. Almost 29 percent of the group articulating the words both at learning and at recall remembered 9 or 10 of the ten words; 10.35 percent of the 'oral to written' group did as well. Approximately 46 percent of the group writing the words in the learning and in the recall tests scored 9 or 10 in the recall test; only 29 percent of the 'written to oral' group did as well. We observe from this that many subjects were disturbed by the changed conditions of response even though the average performance remained practically the same under the two conditions.

Summary

Three conclusions have been formulated with reference to the learning experiments of this study: (1) Learning scores—the number of repetitions required for one perfect recitation—are affected, on the average, by the posture assumed at the time of learning, a slight tendency in favor of the seated posture being evident. (2) Learning scores are a function to some extent, of the sensory mode of presenting the Stimulus series, the auditory method being preferable in the group in which the comparison was possible. (3) Learning scores are independent of the form of the response used in apprehending the material, writing the responses in the practice period having no advantage over speaking them in fixing the associations.

The main results are concerned with the topic of recall, and the following facts are offered as the outcome of the tests of retention: (1) Recall scores—the number of correct responses after an interval of twenty-four hours—are unaffected by a shift in the kinæsthetic situation as produced by the assumption of a different posture at the recall test. Changes in the stimulating situation are ineffectual to this extent in breaking up the recently established associative sequences. (2) Recall scores are lowered and the number of high and perfect scores markedly decreased by a change in the sensory mode of presenting the stimulus words at the recall test. (3) Recall scores are unaffected by a change in the form of the response demanded at the time of the recall test. The number of high scores is reduced with changed conditions but on the

whole it appears that a response once learned can be executed in either the written or oral form with no loss in accuracy.

The theoretical significance of these results lies in their bearing on certain topics widely discussed in the literature of the present day. Many writers, both Gestalt and non-Gestalt, are insisting on the importance of the total stimulating situation in determining the response. We believe our results to be in essential harmony with this doctrine while demonstrating a certain amount of independence in the specific stimulus-response connections. We interpret the failure of the conditions of Experiments I and III to produce marked effects on recall as evidence against a point-for-point connection in the sensory-motor system and at the same time, as evidence which brings out the value of the complete stimulus pattern in determining the response. It has been suggested that learning under both the postural conditions of our experiment was a reaction to a novel, unnatural situation, and that a shift of these conditions at the time of recall was ineffectual, therefore, to the extent that a new situation was not created thereby. In the same way, the request to write or to speak the associated sequence of words produced no conflicting tendencies. On the other hand, a shift in the mode of stimulation produced a real situational difference for the subjects as evidenced by their distinctive learning activity under the two conditions. The response at the time of recall was disrupted accordingly with a real change in the situation.

From the third experiment it appears that we have derived results with human subjects which are in general conformity with Lashley's theory of the equivalence of motor responses. In spite of certain individual differences it appears that the mode of responding can be changed within certain limits with no effect on the speed and smoothness of the induced response. Whether this ready shift from one form to the other is a function of native neural propensities, as suggested by Lashley (**10**) in his experiments on bilateral transfer in the animals of his studies, or whether it is the result of an acquired agility is a matter of individual interpretation. It seems highly probable, however, that our results are a

function partially, at least, of the highly trained college students serving as subjects in our experiments. It is conceivable that such dexterity might not have been demonstrated with elementary school children in the role of subjects or with others in whom the writing and talking responses were less highly automatized at the time of the experiment.

Equivalence of sensory stimuli, in Lashley's terminology (9) is clearly not demonstrated in the present study. It appears that auditory stimuli cannot be substituted for visual stimuli without a loss in effectiveness. It has been suggested that this lack of transposability may well be a function of the differences in training and habits of study of the individual subjects, however. It is possible, therefore, to regard this as a case where the native propensities of the sensory pathways have been modified again through the individual's experience, bringing with it this time a loss in the effectiveness of one of the sensory modes.

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